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DEVELOPMENT AND VERIFICATION OF FIRE TESTS FOR CABLE SYSTEMS AND SYSTEM COMPONENTS

Quarterly Report 4
March 1 - May 31, 1978

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Underwriters Laboratories, Inc.

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ABSTRACT

Experiments were conducted to establish data on the sensitivity of the results to variations of several parameters of the vertical cable tray fire test described in the IEEE Standard 383. Parameters varied were burner-to-cable distance, air input rate and fuel input rate. As a result of these experiments and previous experience, suggestions for revision of IEEE 383 are made with respect to 1) construction of cable trays, 2) test enclosure, 3) type, size and spacing of cable ties, 4) burner position, 5) mesurement of fuel and air rates, 6) flame temperature, 7) initial room temperature, and 8) reporting of results.

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NUREG/CR-0152 (UL-USNC 75 Q2-3)

Development And Verification Of Fire Tests For Cable Systems and Components

I. Introduction

This is the fourth quarterly report covering the period from March 1 through May 31, 1978. During this period, separate-effects experiments which were conducted as a part of Task A of the contract work scope. Specifically, twenty experiments were conducted to refine parameters of the IEEE 383 cable fire test method.

Several separate-effects experiments were conducted previously and described in Report NUREG/CR-0152 (UL-USNC 75 Q2-3). These experiments were conducted retaining similarity to the IEEE 383 test method, but with full cable trays (nominally 40 percent fill) and two burner ignition sources in order to more closely simulate a severe fire condition. However, experiments with one cable type produced results which were extremely variable because of random movements of the cable during burning and therefore, experiments with full fill cable trays were terminated for the present time.

One criticism about the present test method has been that results obtained are not repeatable between tests or reproducible between testing facilities.

Since a need exists for a reproducible cable fire test method, experiments were conducted to refine the values specified in the present IEEE 383 test method. The object of these experiments was to provide a data basis to establish tolerances for various test parameters and to define a test method with more reproducible results.

The parameters which were varied were 1) burner-to-tray distance, 2) air input rate, and 3) fuel input rate. The plan was to observe the effect of changing the parameters from the values specified in present IEEE 383. Also, since the only measure of cable performance described in the present IEEE 383 test method is the extent of cable damage, the use of cable-jacket temperatures developed during the experiment as a supplemental performance measure was investigated. Cable jacket temperatures might be used to determine actual extent of cable damage, and might also provide a measure of the linear rate of cable deterioration.

II. Experimental Procedure

A. Facility

The cable experiments were conducted inside a heated brick building 37 ft wide, 67 ft long and 21 to 24 ft high as shown in Figure 1. The building was ventilated and free from excessive drafts and spurious air currents, although no specific draft measurements were made.

During the cable experiments all exterior doors were closed and all roof vents in the building were opened. The roof vents were ducted to an exhaust and smoke incineration system. The nominal volumetric flow rate through the afterburner system was 16,000 cfm, which corresponds to one air change every 4 min. There was sufficient air leakage that atmospheric pressure was maintained inside the building while the incinerators were in operation.

B. Apparatus

The burner apparatus consisted of one burner head and a Venturi air-fuel mixer as described in IEEE 383-1974. The burner head was a 10 in. wide, 11-55 drilling, ribbon burner, and the mixer was a No. 14-18. Both were manufactured by the American Gas Furnace Co. Bottled commercial grade propane and laboratory compressed air were used in the experiments. The heating value of the commercial grade propane was 2,514 BTU/ft_3.*

Cable experiments were conducted using open-ladder type cable trays, 8 ft long and 12 in. wide. The side channels were 3-3/8 in. deep with 1 in. flanges and fabricated from No. 16 MSG (0.060 in. thick) cold-rolled steel. The nominal 0.125 in. thick (No. 10 MSG) ladder rungs were 1 in. wide with 1/2 in. legs, and were tack-welded to the side rails at 9 in. intervals. Steel wire ties formed from No. 16 SWG (0.062 in. thick) were used to fasten each cable to various rungs of the cable trays as shown in Figure 2.

*Value obtained by test with a recording calorimeter and a sample of propane from the same lot used in testing.

C. Enclosure

An enclosure 8 by 8 by 8 ft high was used to isolate the sample from extraneous environmental effects as shown in Figure 3. It was formed by four steel-framed wall sections, 8 ft square, to which 1/2 in. Marinite boards were fastened. The sections were clamped together at the four corners so that each could easily be raised or lowered independently. The interior surfaces of the enclosure were painted flat black. Several observation windows and an access door were provided.

D. Samples

The cables used in these experiments were stranded seven (copper) conductor, No. 12 AWG with three combinations of insulation and jacket materials. Identification of cable materials was on the basis of information provided by the suppliers. The cables are identified in this report only by a code number in the description of the experiments to avoid association of the results with proprietary products at this time. Descriptions of the cables, without identification of the code numbers, are given in Table I.

E. Instrumentation

Type K, Chromel-Alumel thermocouples were used to measure the air and propane temperatures before the mixer and the cable jacket temperatures.

Pressures of the fuel and air within the burner piping before the mixer were measured with differential pressure manometers. Volumetric flow meters were used to monitor propane and combustion-air flow rate.

A thermometer and a barometer were used to measure the ambient air temperature and barometric pressure of the test room prior to each experiment.

F. Method

The experiments were conducted in the sequence shown in Table 2 and in general accordance with the method described in IEEE-383-1974, paragraph 2.5.

Cables were installed in a single layer filling the center 6 in. portion of the tray, and spaced approximately 1/2 cable diameter apart. Since the cable diameter was different for each cable type, the number of lengths of cables installed into the tray was different for each cable type. Each length of cable was fastened to ladder rungs with No. 16 SWG (0.062 in. thick) steel wire at approximately 18 in. O.C. The number of cables per tray and location of fasteners are shown in Figure 2.

The tray was installed vertically in a steel base frame with the rear surface of the cable tray rungs facing the burner. The burner face was positioned 3 in. away from (except in Experiments 5, 6, 11 and 12) and perpendicular to the rear of the cable tray. The center of the burner face was located 24 in. above the base of the tray and midway between ladder rungs.

The temperatures of the cable jacket material were measured in ten experiments. In each of these experiments one cable was instrumented with 12 thermocouples as shown on Figure 4. Each thermocouple was recessed into a notch in the cable jacket, with the notch then filled with a one-part silicone adhesive to fasten the thermocouple to the cable.

The test room was heated to approximately 63 F before the afterburner system was operated in Experiments 1-17. However, no heat was supplied to the test room for Experiments 18-20 since the natural outside air conditions produced the desired room temperature.

To initiate each experiment, a pilot burner flame was ignited. The propane gas and air flows were adjusted to obtain pressures within the specifications outlined in IEEE 383-1974 and/or to obtain the desired volumetric air and fuel inputs under consideration. After the required flows were obtained the experiment was initiated. Specimens were subjected to the burner flame for a 20 min duration after which the burner flame was extinguished.

Throughout each experiment, visual observations were made of the condition of the cable material, flame travel, and other developments pertinent to the fire performance of the cables. Each experiment was concluded when all fire activity had ceased.

III. Results

A. Visual Observations During Experiments

A summary of visual test observations for each cable type are given below. Graphs of maximum flame height versus time are shown in Figures 5-10.

Type I

The cable jacket material melted in advance of the propagating flame. Although the cable jacket material melted, the cable did not fuse together into a single cable mass in the fire region. No fall off of flaming material or other dripping or sparking was observed. As the flames traveled up the tray, the burning cable jacket/insulation material produced white ash. Small pieces of the ash gradually fell to the floor.

Type II

The cable jacket material discolored, blistered and cracked in advance of the flame. No melting of the cable jacket was observed. The outer surface of the cable jacket formed small scales, approximately 1/16 in. in diameter and smaller. A small amount of expansion of the cable insulation and/or jacket materials was observed to occur, although not sufficient to close the space between adjacent cables. While the cable material was flaming crackling noise issued from the burning cable, although no noticable loss of surface particles occurred. As the flames traveled up the tray, the burning cable jacket/insulation material produced white ash. Small pieces of the ash gradually fell to the floor.

Type III

The cable jacket/insulation material swelled in the fire area closing the space between the cables. The ignition flame was then unable to penetrate through the cable mass to the cable front surface. The ignition flame was able to curl about the sides of the cable mass to the front surface of the end cables. In the fire area crackling and popping sounds were audible as some small (approximately 1/16 in. diameter) particles popped away from the cable. The color of the burned cable jacket was a light gray.

Cable Jacket Temperatures - Temperature records for each experiment in which cable jacket thermocouples were installed are shown in Tables 3-12. Isothermal graphs for each instrumented cable experiment are shown in Figures 11-20.

Observations After Test - Maximum cable damage height for each cable was recorded as shown in Table 13. The maximum and average cable damage heights for each experiment is summarized in Table 14.

IV. Discussion

Several effects were observed when the test parameters were varied.

Experiments 1 through 4 were conducted to provide an estimate of the repeatability of the results for fixed test conditions. Heights of damage on individual cables in each experiment are shown in Table 3, and the maximum height of damage for each experiment is shown in Table 14. It is seen that for Experiments 1-3, the variation of the maximum damage height was from 68 to 71 in., whereas the maximum damage height in Experiment 4 was 87 in. However, Experiment 4 is suspect for the following reason. Room temperature prior to the experiment had inadvertantly been allowed to rise to about 95 F, and then cooled to 64 F by admitting outside air. It is possible that parts of the cable, cable tray, and enclosure were still above room temperature at the start of the experiment, thus increasing the height of damage in that experiment. For this reason, only Experiments 1-3 are being used to estimate the basic repeatibility of the height of damage, which is estimated to be ±1-1/2 in.

As shown in results of Experiments 5 and 6, varying the burner distance ±1/2 in. from the specified 3 in. has a significant effect on cable performance. About a 10 in. difference in height of cable damage was recorded between Experiments 5 and 6. However, little difference in height of cable damage was observed between Experiments 11 and 12 where the burner distance was varied ±1/8 in.

In Experiments 7 and 8, the air input rate was varied plus 10 percent and minus 6 percent, respectively. The results of these tests show that little difference in cable damage is produced by such a variation in the supply air. This is to be expected, since the air/fuel ratio of the standard ignition flame is approximately 6/1, whereas the stoichiometric air/fuel ratio is about 23/1. With such a fuel-rich mixture, slight variations in the amount of air should not have a significant effect on the nature of the flame heat output.

The fuel input rate was varied in Experiments 9, 10, 13 and 14. A plot of height of cable damage for each of the experiments is shown in Fig. 21. As shown, there is a tendency for increasing cable damage with decreasing fuel input. Approximately a 10 in. difference in cable damage was observed between Experiments 9 and 10 in which the fuel input was varied from 65,000 to 70,000 Btu/hr. However, only a 1 in. difference in cable damage was observed when the fuel input was varied between 71,650 and 67,800 Btu/hr.

As shown in Table 15, initial room temperature for all of the experiments was between 57 and 69 F. Additional room heating was required to obtain the desired room temperatures in Experiments 1-17. Weather conditions produced initial room temperatures in the 60 F range without additional heating in Experiments 18-20.

Visual observations and cable damage in previous cable fire tests suggest that a significant difference in results may be caused by a large variation in initial room temperature. Four cable fire tests according to IEEE 383 were conducted as part of another investigation, and are described in UL Reports, Subject 1277 dated April 18, 1978; and Subject 1277-2, dated June 23, 1978. A summary of the results is shown in Table 16.

The four tests were conducted on one cable type with samples obtained from one cable reel. Besides the variations of initial room temperatures, barometric pressure and humidity, the only difference between Experiments 1-2 and 3-4 was the spacing of cable ties and burner height. However, after allowance for the burner height, Experiments 3 and 4 sustained greater cable damage than did Experiments 1 and 2, which were conducted at lower initial starting temperatures.

In ten of the experiments, cable jacket temperatures were recorded. In Figures 11-20, cable jacket temperatures are plotted on a height versus time graph. These plots may provide information as to the rate of cable burning in each experiment. A comparison of this data with the observed maximum flame height versus time graphs, as shown in Figures 5-10, indicates that there may be a useful correlation between the recorded cable jacket temperature and the observed cable burning. Also, Figures 11-20 suggest that cable damage corresponds with cable jacket temperatures in the 300-400 F range.

Since only a limited number of experiments were conducted, additional experiments would be required to investigate the significance of quantitative measurements of cable jacket temperature. However, the qualitative data on jacket damage is sufficient for establishing test parameter tolerances.

V. Recommendations

It is suggested that the fire test procedure described in NRC Regulatory Guide 1.131 be revised to better define, and elaborate on certain items which presently are only mentioned or excluded entirely. These items are A) construction of cable trays, B) test enclosure, C) type, size and spacing of cable ties, D) tolerance on burner position, E) monitoring of fuel and air input rates, F) flame temperature, G) initial room temperature, and H) reporting of results.

A. Cable Trays

The type of cable tray used has a significant effect on the fire performance of the cables. The cable tray to be used should be completely specified as to its size and construction, including the shape, dimensions and spacing of ladder rungs. Although any standard ladder tray would be adequate, the cable tray described in this Report has been used extensively with good results, and is a reasonable choice for standardization.

B. Enclosure

Since the tests should be free from excessive drafts and spurious air currents, the document should be revised to define the test enclosure. The enclosure used in this investigation seems to provide adequate shelter from superficial air currents within the test room. Also, the rate exhaust from the room should be established. A value to 1800 cfm is suggested as a conservative value, based upon the results of previous experiments in this investigation as reported in NUREG/CR-0152.

C. Cable Ties

The spacing and type of cable ties is very important in obtaining reproducible test results. It is necessary that steel tie wire be specified as the fastening means. When plastic or other low melting temperature material is used as fasteners, the cable usually breaks loose in the fire area. The ensureing random movements of the cables produce significant variability in the results. It is suggested that No. 16 SWG steel wire ties be used to fasten each cable every 18 in. along the cable tray.

D. Burner Position

Presently, the IEEE test method specifies that the burner face shall be 3 in. behind and approximately 2 ft above the bottom of the tray. The sensitivity tests have shown that variations of $\pm 1/8$ in. in the burner-to-tray distance do not produce significant changes in the maximum height of damage. It is therefore suggested that the Standards specify a distance of $3 \pm 1/8$ in. between the burner face and the cable tray.

Although the effect of burner height was not investigated, it seems certain that proximity of the burner to a ladder rung would have a significant effect on the results. Additionally, the height above the bottom of the tray to which damage extends will obviously depend on the height of the burner above the bottom of the tray. For both reasons, it is suggested that the height of the burner be specified in the Standard as $24 \pm 1/8$ in.

E. Fuel and Air Input Rates

The present method of monitoring fuel and combustion air input rate is by measuring the pressure of each in the supply lines before the mixer and measuring the flame temperature. Previous experience has shown that monitoring pressure is a coarse means of regulating the ignition flame since any restrictions in the line, changes in density of the fuel and air, and the heat produced by the burning cable have significant effects on the recorded pressures. Use of rotameters in lieu of the manometers, with compensation for the gas densities provides an accurate means of monitoring fuel and air flow rates.

The Standard should specify that the tests are to be conducted with a fuel input rate of 70,000 ($\pm$1,600) Btu/hr and an air input rate of 163 ($\pm$10) SCFH.

F. Flame Temperature

The flame temperature requirement should be deleted since it is a very difficult quantity to measure.

G. Initial Room Temperature

Although we presently do not have a great quantity of data, it is suspected that initial room temperature has a significant effect on results.

The present tests, conducted with initial room temperatures between about 58 and 69 F, suggest that variations over this range do not significantly affect the results. Until further information becomes available, it is suggested that the Standard specify a tolerance of ±5 F for initial room temperature, which should correspond with initial cable temperature. The center value of the initial room temperature should probably be specifed as 75 F for maximum convenience.

H. Reporting of Results

A definition of cable damage should be included in the Standard. Although more or less sophisticated determinations of jacket and insulation properties might be conceived for assessing damage, these do not appear to be necessary. A definition of damage as melting, blistering, or charring appears to be sufficient for this test.

These suggestions are based on results of a limited number of experiments. If greater detailed quantitative results are desired concerning the repeatability and reproducibility of the test, further experimentation would be required. It is recommended, therefore, that round-robbin testing be undertaken to obtain this additional data.

Although reporting of cable jacket temperatures appears to be beneficial, more experimentation would have to be conducted before any specific proposal could be made. However, the techniques and time required for proper placement of the cable jacket temperatures may be too demanding for inclusion of this measurement in a standard test of this nature at this time.

Table 1 Cable Description

Designation	Cable Cross Section Diameter, In.	Insulation/Jacket Material	Approximate Conductor Insulation/ Jacket Thickness, In.	Cable Jacket Material	Approximate Cable Jacket Thickness, In.
EPR-Hypalon/Hypalon	0.785	Ethylene propylene rubber/chloro-sulphonated poly-ethylene	0.028/0.017	Chlorosulphonated polyethylene	0.134
PVC-Nylon/PVC	0.515	Polyvinyl chloride/ nylon	0.022/0.006	Polyvinyl chloride	0.050
XLPE/Neoprene	0.618	Crosslinked poly-ethylene	0.044/-	Polychloroprene rubber	0.068

Table 2 IEEE 383 Cable Experiments

Experiment No.	Cable Type	Fuel Input (BTU/Hr)	Air Input (SCFH)	Air/Fuel Ratio	Burner Distance (In.)	Cable Jacket Temperature Measurement
1	I	70,000	163	5.9/1	3	Yes
2	I	70,000	163	5.9/1	3	Yes
3	I	70,000	163	5.9/1	3	Yes
4	I	70,000	163	5.9/1	3	Yes
5	I	70,000	163	5.9/1	3-1/2	No
6	I	70,000	163	5.9/1	2-1/2	No
7	I	70,000	180	6.5/1	3	No
8	I	70,000	153	5.5/1	3	No
9	I	65,000	163	6.3/1	3	No
10	I	75,000	163	5.5/1	3	No
11	I	70,000	163	5.9/1	3-1/8	No
12	I	70,000	163	5.9/1	2-7/8	No
13	I	71,650	163	5.7/1	3	No
14	I	67,800	163	6.0/1	3	No
15	II	70,000	163	5.9/1	3	Yes
16	II	70,000	163	5.9/1	3	Yes
17	II	70,000	163	5.9/1	3	Yes
18	III	70,000	163	5.9/1	3	Yes
19	III	70,000	163	5.9/1	3	Yes
20	III	70,000	163	5.9/1	3	Yes

Table 3 Cable Jacket Temperatures Experiment 1
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	64	57	64	57	66	64	57	66	57	57	55	55
1	1349	348	219	397	110	171	91	110	100	-	108	65
2	1460	364	294	453	136	210	106	126	124	-	119	71
3	1488	430	403	529	183	274	126	143	143	91	141	77
4	1347	420	499	639	400	406	171	188	186	108	162	88
5	1557	476	581	708	388	519	208	221	234	123	186	98
6	1615	537	575	731	442	615	236	230	258	132	191	100
7	1223	662	476	-	409	595	214	101	252	134	197	106
8	1306	582	332	-	364	517	171	93	230	130	193	101
9	1434	489	307	-	241	408	175	84	217	120	186	99
10	1568	484	306	-	217	363	165	77	201	117	182	98
11	1425	476	305	-	200	341	156	73	193	114	175	98
12	1212	473	307	-	195	334	154	67	191	112	174	97
13	1343	462	296	-	187	319	148	65	186	110	174	93
14	1497	456	290	-	187	311	145	64	185	110	174	92
15	1202	431	258	-	177	296	141	61	180	110	169	91
16	1469	431	296	-	175	294	134	59	175	110	165	90
17	1335	428	278	-	173	282	132	55	175	105	165	89
18	1529	415	300	-	173	276	132	55	174	105	162	88
19	1438	408	283	-	171	274	132	55	182	104	160	88
20	1319	406	261	-	169	274	132	55	184	101	160	88

Table 4 Cable Jacket Temperatures Experiment 2
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	60	60	66	57	67	60	-	57	77	51	64	66
1	1504	1549	373	714	161	174	121	99	130	104	90	86
2	1579	1624	607	808	217	217	152	134	165	134	108	99
3	1530	1571	981	948	305	319	204	165	212	152	143	112
4	1561	1548	1166	1201	554	453	283	230	283	195	173	234
5	1526	1593	1252	64	820	769	409	319	314	234	186	156
6	1606	1606	1308	55	1010	769	449	364	306	252	195	177
7	1615	1615	821	46	1032	756	431	372	278	252	186	186
8	1482	1548	607	46	506	542	364	332	252	230	186	182
9	1517	1606	595	46	386	449	341	301	234	221	177	177
10	1200	1593	533	46	373	863	319	287	230	212	221	173
11	1054	1438	542	46	355	799	305	274	221	208	173	169
12	1257	1650	684	46	296	884	292	270	217	204	169	169
13	1222	1526	542	46	323	341	279	252	208	195	165	165
14	1482	1615	641	46	319	328	269	252	208	195	165	165
15	1200	1615	628	46	319	296	261	252	199	186	165	165
16	1394	1504	684	41	296	314	252	239	195	186	161	161
17	1504	1504	585	41	314	296	239	230	195	186	156	161
18	1540	1438	607	41	319	296	234	230	195	182	156	156
19	1504	1460	607	41	296	292	230	230	195	182	156	152
20	1579	1517	607	41	327	292	225	225	190	182	156	152

Table 5 Cable Jacket Temperatures Experiment 3
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	60	60	-	60	64	55	51	55	60	57	60	77
1	1593	598	453	300	190	173	143	121	112	100	95	90
2	1505	795	598	108	247	217	169	143	134	121	108	100
3	1416	1412	778	104	390	305	225	169	156	138	121	117
4	1521	1505	841	112	585	426	296	212	186	160	143	125
5	1438	1482	867	598	624	519	359	247	217	186	160	143
6	1329	1373	850	812	675	593	399	269	234	195	169	152
7	1570	1200	816	705	675	546	372	274	234	190	169	152
8	1222	1061	714	576	537	395	309	260	212	182	165	147
9	1351	926	667	506	431	336	274	252	195	169	160	143
10	1394	905	649	475	386	287	256	237	190	165	156	143
11	1705	947	649	475	363	296	252	234	186	165	152	143
12	1526	880	628	449	345	283	238	230	182	160	147	143
13	1265	816	615	440	336	274	234	221	182	160	147	138
14	1287	816	606	431	323	265	230	212	173	156	147	138
15	1570	774	589	431	318	260	225	208	173	152	143	138
16	1438	778	606	435	314	256	221	208	169	152	143	138
17	1222	761	580	413	309	252	217	208	169	147	143	138
18	1570	756	546	417	300	252	212	204	165	147	143	134
19	1450	735	541	413	296	252	212	204	165	147	143	134
20	1482	714	537	408	296	247	208	199	165	143	143	134

Table 6 Cable Jacket Temperatures Experiment 4
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	55	55	60	75	55	60	55	77	55	94	55	55
1	1638	386	520	278	152	169	143	93	104	121	113	99
2	1330	515	547	346	195	199	165	108	121	139	126	99
3	948	778	865	589	292	283	208	139	143	161	148	121
4	1268	939	926	832	431	431	300	187	187	187	167	143
5	1393	956	948	816	628	533	391	261	234	230	199	165
6	1415	1045	964	637	693	632	554	319	300	259	220	187
7	757	986	645	714	671	667	736	395	328	283	243	208
8	1437	985	624	554	804	641	863	524	445	359	287	234
9	1086	981	607	528	1074	641	884	624	520	409	309	252
10	1188	896	589	515	581	619	799	706	549	445	328	265
11	1393	842	585	515	507	541	748	684	541	454	328	259
12	1437	799	585	489	453	467	515	624	520	377	300	257
13	948	744	563	444	409	431	395	489	453	341	274	243
14	1265	752	563	453	422	399	346	431	413	323	260	230
15	1265	714	520	418	368	373	319	399	386	309	247	226
16	884	706	547	427	355	350	300	364	359	300	238	213
17	1308	736	520	395	341	328	278	332	332	283	234	208
18	1286	795	511	399	319	300	257	309	314	319	226	195
19	1201	795	520	391	319	311	252	265	300	265	221	190
20	1265	778	497	386	314	287	252	274	274	252	213	186

Table 7 Cable Jacket Temperatures Experiment 15
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	57	60	66	55	57	54	48	55	57	55	55	52
1	1011	454	243	37	143	143	121	95	108	95	95	51
2	1180	515	291	234	160	164	134	104	112	108	99	81
3	1062	555	305	252	177	173	138	113	121	121	104	95
4	965	714	318	270	190	164	147	121	134	126	108	100
5	965	859	336	296	212	204	160	135	117	135	121	104
6	990	1032	368	319	230	221	169	135	147	135	126	113
7	1015	1019	466	382	265	247	190	152	156	152	138	121
8	1138	905	628	449	296	265	204	165	164	165	143	126
9	1145	948	837	498	323	283	221	178	177	165	152	135
10	1158	1007	901	537	345	296	225	182	182	174	152	139
11	1231	1074	930	546	359	327	234	181	187	178	138	143
12	1300	1104	930	542	363	314	234	195	187	195	152	143
13	1338	1104	943	520	359	309	234	195	187	174	152	143
14	1333	1159	1011	515	359	309	230	195	187	178	152	148
15	1330	1163	1040	515	350	305	230	195	187	178	152	143
16	1321	1176	1074	515	341	300	230	195	187	178	152	143
17	133	1189	1091	515	341	296	230	195	187	178	152	143
18	1343	1202	1108	511	332	291	225	195	187	178	152	143
19	1343	1270	1176	515	327	291	230	195	187	178	152	143
20	1352	1287	1201	511	323	283	225	195	187	178	152	143

Table 8 Cable Jacket Temperatures Experiment 16
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	60	56	-	56	54	73	55	55	55	55	53	56
1	1460	431	238	199	134	1637	138	99	117	95	77	95
2	761	511	274	217	147	1286	138	112	121	99	90	99
3	697	502	283	234	164	1108	143	117	125	104	95	104
4	680	519	287	247	177	671	147	125	130	108	99	112
5	688	697	300	260	190	871	156	138	138	121	104	117
6	863	778	323	283	208	744	164	143	143	125	112	125
7	820	1053	354	318	225	905	177	147	147	130	112	130
8	1342	1074	449	399	247	875	204	169	169	143	125	138
9	854	761	692	413	274	841	204	177	169	147	134	143
10	909	863	718	435	296	947	212	186	177	156	143	147
11	841	926	854	449	314	833	212	186	177	160	147	151
12	930	964	867	462	323	905	208	195	182	160	147	151
13	930	989	871	484	336	918	230	204	190	164	147	156
14	947	998	854	458	332	956	225	204	186	160	151	160
15	989	1023	841	453	327	989	229	204	186	164	151	160
16	1006	1044	854	453	323	1006	221	204	186	164	151	160
17	994	1049	863	444	318	985	217	204	182	160	151	160
18	1006	1057	880	453	314	994	208	204	182	160	151	160
19	960	1053	909	444	309	977	212	204	182	160	151	160
20	968	1070	939	444	300	964	208	208	182	160	147	160

Table 9 Cable Jacket Temperatures Experiment 17
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	64	66	55	66	64	64	64	-	62	66	62	66
1	1615	413	248	190	147	138	125	147	125	104	99	99
2	1544	511	301	238	182	164	143	164	138	121	108	108
3	1710	576	323	260	199	182	160	182	143	138	117	121
4	1638	602	332	269	208	186	169	190	147	143	125	125
5	1615	863	255	287	230	199	177	195	151	143	130	130
6	1710	880	400	318	247	212	186	208	164	151	138	138
7	1683	981	511	386	278	243	208	225	177	164	147	147
8	1660	867	620	475	323	274	234	243	190	182	156	160
9	1593	927	897	563	363	309	252	256	208	186	164	164
10	1575	1011	935	624	408	332	269	274	225	195	177	173
11	1580	1079	1019	671	422	345	274	274	225	199	177	177
12	1478	1185	994	752	408	341	274	279	221	208	182	177
13	1535	1159	1007	701	399	332	274	279	212	208	182	182
14	1482	1163	1019	688	386	327	269	279	208	204	182	182
15	1513	1137	1024	671	372	318	265	279	208	204	182	182
16	1465	1159	998	680	363	314	260	279	204	199	186	182
17	1434	1159	1011	662	359	300	252	279	199	195	186	182
18	1307	1146	914	671	354	300	252	274	204	195	186	182
19	1382	1219	918	671	345	296	252	274	199	190	182	182
20	1352	1184	948	649	341	291	247	274	199	190	182	182

Table 10 Cable Jacket Temperatures Experiment 18
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	-	-	-	69	69	69	68	68	61	61	61	69
1	1456	407	235	170	118	129	114	98	81	79	75	89
2	1508	403	275	200	137	140	127	107	88	86	81	97
3	1559	339	240	206	151	149	142	118	96	94	87	106
4	1549	324	242	225	171	160	154	128	103	100	93	93
5	1557	322	254	236	190	171	166	139	110	107	98	119
6	1460	327	271	247	208	181	174	148	116	112	103	125
7	1576	339	287	261	223	192	183	158	123	119	108	131
8	1513	350	303	272	236	203	192	166	128	125	113	137
9	1497	361	321	283	247	211	200	174	133	126	117	142
10	1266	373	332	294	259	220	208	181	167	162	122	147
11	1062	380	340	299	269	227	216	189	174	167	152	152
12	1148	389	347	306	279	237	222	195	179	170	157	156
13	1050	399	359	315	287	243	227	201	184	169	161	160
14	681	410	372	325	296	248	232	207	189	176	166	164
15	418	418	381	329	302	253	238	213	195	183	170	168
16	473	429	387	335	307	258	240	216	199	185	173	170
17	598	447	397	343	314	266	247	220	203	188	176	173
18	674	456	403	345	319	270	250	223	207	193	178	175
19	944	456	403	346	323	271	251	225	209	201	181	177
20	617	456	403	348	327	272	253	227	210	194	182	178

Table 11 Cable Jacket Temperatures Experiment 19
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	-	-	-	69	69	69	70	70	65	65	69	70
1	1562	293	188	153	128	127	121	103	101	96	90	86
2	1639	372	226	182	150	143	139	115	112	107	99	95
3	1609	347	235	197	169	154	152	127	122	116	106	103
4	1467	336	240	210	186	164	164	137	129	124	113	110
5	1592	337	257	229	204	176	172	147	137	130	119	117
6	1581	341	272	245	219	187	182	156	145	138	126	123
7	1577	349	286	260	233	198	191	166	153	145	132	129
8	1554	357	295	269	244	205	198	173	159	151	138	135
9	1489	368	307	278	255	214	205	179	165	155	143	139
10	1619	379	319	286	261	219	208	184	169	159	147	144
11	1644	392	331	293	270	227	216	191	175	165	152	148
12	1629	405	343	302	280	236	224	198	181	170	157	153
13	1612	415	350	307	284	240	227	201	184	172	160	155
14	1627	429	358	314	290	245	232	207	189	177	164	160
15	1662	436	361	316	294	249	234	211	192	180	167	163
16	1650	447	370	324	297	254	237	212	194	181	169	165
17	1639	453	380	329	300	255	238	215	197	184	171	167
18	1637	462	381	332	302	256	239	215	198	185	173	168
19	1645	462	380	330	302	255	238	215	197	185	173	169
20	1534	463	379	331	300	254	238	214	197	185	174	169

Table 12 Cable Jacket Temperatures Experiment 20
(Degrees F)

Time (Min)	Height (In.) 30	36	42	48	54	60	66	72	78	84	90	96
Pre-test	68	68	68	68	68	68	68	67	67	67	67	67
1	1453	1543	225	158	132	118	114	100	100	93	85	89
2	1452	1361	257	190	150	134	131	111	112	104	-	98
3	1344	1672	244	200	165	146	142	121	120	112	100	105
4	977	1724	253	219	180	157	151	130	126	120	106	112
5	1360	1768	265	233	198	168	160	139	133	126	-	117
6	1362	1770	283	249	213	181	171	148	141	131	-	122
7	1348	1748	299	261	228	192	181	157	148	138	-	128
8	1218	1663	310	269	238	200	188	164	154	144	-	132
9	1111	1760	325	282	250	210	196	172	160	149	134	137
10	1130	1747	342	294	262	220	204	179	166	155	141	142
11	1183	1731	354	305	272	228	211	185	171	158	145	145
12	1220	1738	364	309	278	234	217	190	175	163	148	148
13	995	1605	374	317	286	240	220	194	178	165	151	151
14	1048	1763	383	323	289	244	221	198	180	167	154	153
15	1206	1521	389	326	295	249	228	203	183	170	157	155
16	889	1758	394	330	299	253	230	206	186	173	160	158
17	1113	1768	396	336	303	257	233	210	189	175	162	160
18	1147	1706	398	340	307	261	236	212	193	177	164	161
19	1172	1767	398	342	309	262	237	212	194	179	165	161
20	718	1205	398	341	307	261	235	211	191	177	165	160

Table 13 Maximum Height Of Cable Damage

Cable No.	Experiment No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Front Surface																				
1	65.0	66.0	62.5	78.0	70.5	60.0	63.0	65.0	72.0	64.0	74.0	70.0	66.0	72.0	46.5	47.5	48.0	41.0	47.0	38.0
2	67.0	67.5	64.0	84.0	71.0	61.0	65.0	68.0	75.5	64.0	74.0	74.0	69.5	72.0	47.5	47.5	49.0	39.0	40.0	37.0
3	68.5	71.0	65.5	85.0	72.0	63.0	64.0	68.0	76.0	66.0	74.0	76.0	70.0	72.0	48.0	47.5	50.5	39.0	37.0	37.0
4	69.0	71.0	66.2	85.0	72.0	63.0	66.0	68.0	78.0	66.0	74.0	76.0	70.5	72.0	48.0	47.5	50.0	39.0	39.0	37.0
5	68.0	70.5	68.0	87.5	72.5	63.0	67.5	68.0	78.0	67.0	74.0	76.0	71.0	72.0	48.0	48.0	51.0	39.0	42.0	40.0
6	68.0	69.5	67.5	85.0	71.5	63.0	67.5	68.0	78.0	68.0	73.0	76.0	70.5	72.0	48.5	48.0	53.0	45.0	47.0	48.0
7	69.0	70.0	64.0	84.0	72.0	63.0	69.0	68.0	75.0	68.0	73.0	76.0	71.0	70.0	50.0	48.0	52.5			
8	67.0	69.0	63.5	81.0	71.0	60.0	65.0	65.0	74.0	66.0	70.0	76.0	69.0	69.0						
Rear Surface																				
1	55.0	57.0	-	79.0	67.0	51.0	55.0	57.0	71.0	61.0	73.0	72.0	64.0	72.0	46.5	46.0	46.0	45.0	49.0	44.5
2	55.0	62.0	-	81.0	67.0	54.0	54.0	58.0	69.0	63.0	73.0	72.0	64.5	72.0	46.5	46.0	46.0	43.0	49.0	46.0
3	60.0	63.0	-	82.0	70.5	54.0	57.0	60.0	72.5	64.0	73.0	74.0	68.5	72.0	47.5	46.5	46.0	46.0	45.5	46.0
4	61.0	63.0	-	86.0	70.5	54.5	60.0	60.0	72.0	64.0	73.0	74.0	69.5	72.0	48.0	47.5	48.0	46.0	45.5	46.0
5	62.0	63.0	-	82.0	69.0	54.0	59.0	60.0	72.0	64.0	73.0	74.0	69.5	72.0	48.0	47.5	48.0	46.0	45.5	47.0
6	60.0	63.0	-	81.0	69.0	53.0	59.0	60.0	72.0	64.0	73.0	74.0	69.0	72.0	48.5	47.5	50.0	46.0	45.5	49.0
7	56.5	63.0	-	81.0	67.5	53.0	58.0	60.0	72.0	60.0	73.0	74.0	67.5	68.0	48.5	47.5	50.0			
8	55.5	63.0	-	81.0	62.0	50.0	60.0	58.0	70.5	60.0	73.0	72.0	67.0	65.0						

Table 14 Cable Damage Summary

Experiment No.	Maximum Cable Damage Height (In.)	Average Cable Damage Height (In.)
1	69.0*	67.7*
2	71.0*	69.3*
3	68.0*	65.2*
4	87.0*	83.6*
5	72.5*	71.6*
6	63.0*	62.0*
7	69.0*	65.9*
8	68.0*	67.2*
9	78.0*	75.8*
10	68.0*	66.1*
11	74.0*	73.2*
12	76.0*	75.0*
13	71.0*	69.7*
14	72.0*	71.4*
15	50.0*	48.0*
16	48.0*	47.7*
17	53.0*	50.6*
18	46.0**	45.3**
19	49.0**	46.6**
20	49.0**	46.4**

*Front surface
**Rear Surface

Table 15 Initial Temperatures

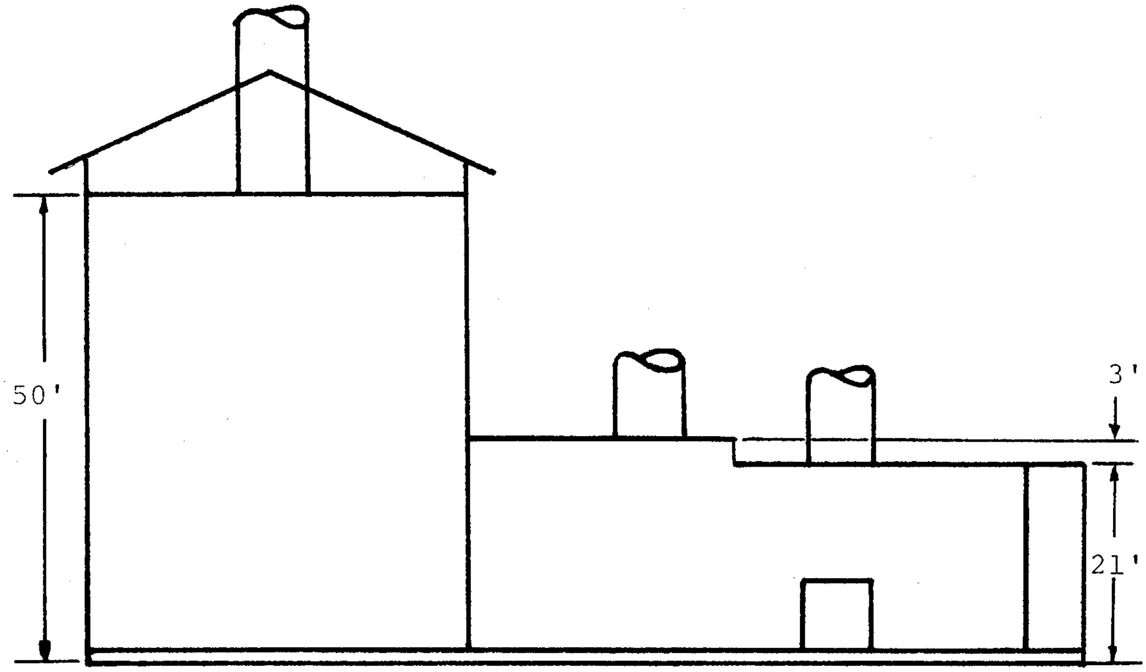
Experiment No.	Average Initial Cable Jacket Temperature	Initial Room Air Temperature
1	60	64
2	62	58
3	60	59
4	63	64
5	-	64
6	-	63
7	-	64
8	-	65
9	-	61
10	-	65
11	-	65
12	-	64
13	-	64
14	-	62
15	56	63
16	57	64
17	63	64
18	66	67
19	68	69
20	68	67

Table 16 Summary of Supplemental Cable Experiments

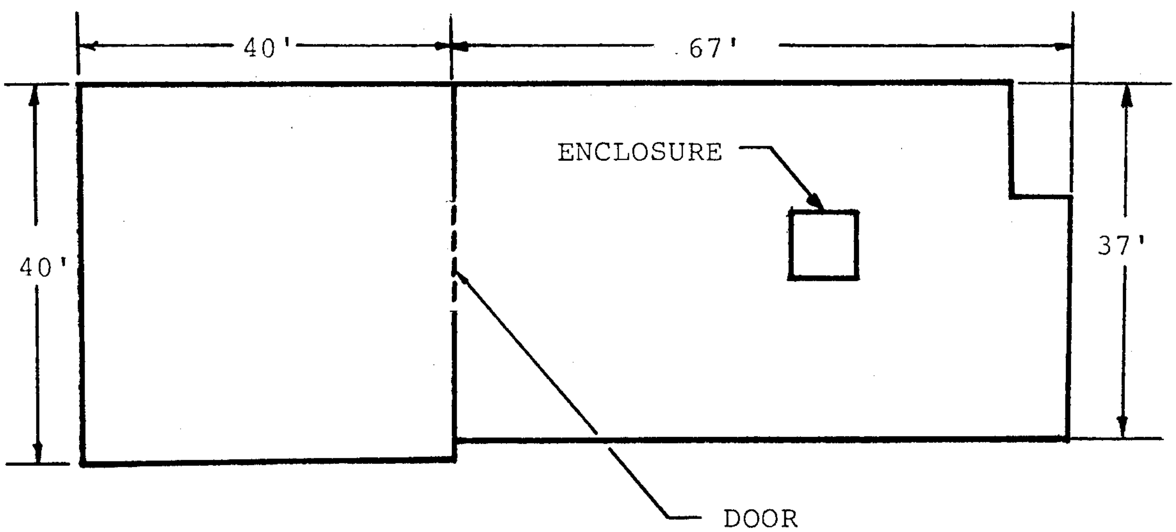
	Exp. 1*	Exp. 2*	Exp. 3*	Exp. 4*
Cable tie spacing (in.)	27	27	18	18
Initial room temperature (F)	42	43	70	72
Barometric pressure (In./Hg)	29.58	29.60	29.34	29.35
Relative humidity	38	38	48	46
Maximum height of cable damage (in.)**	72	78	82	83

*Experiment numbering from Reports Subjects 1277 and 1277-2.

**Adjusted to allow for differences in burner height.



ELEVATION VIEW



PLAN VIEW

Figure 1 - Facility

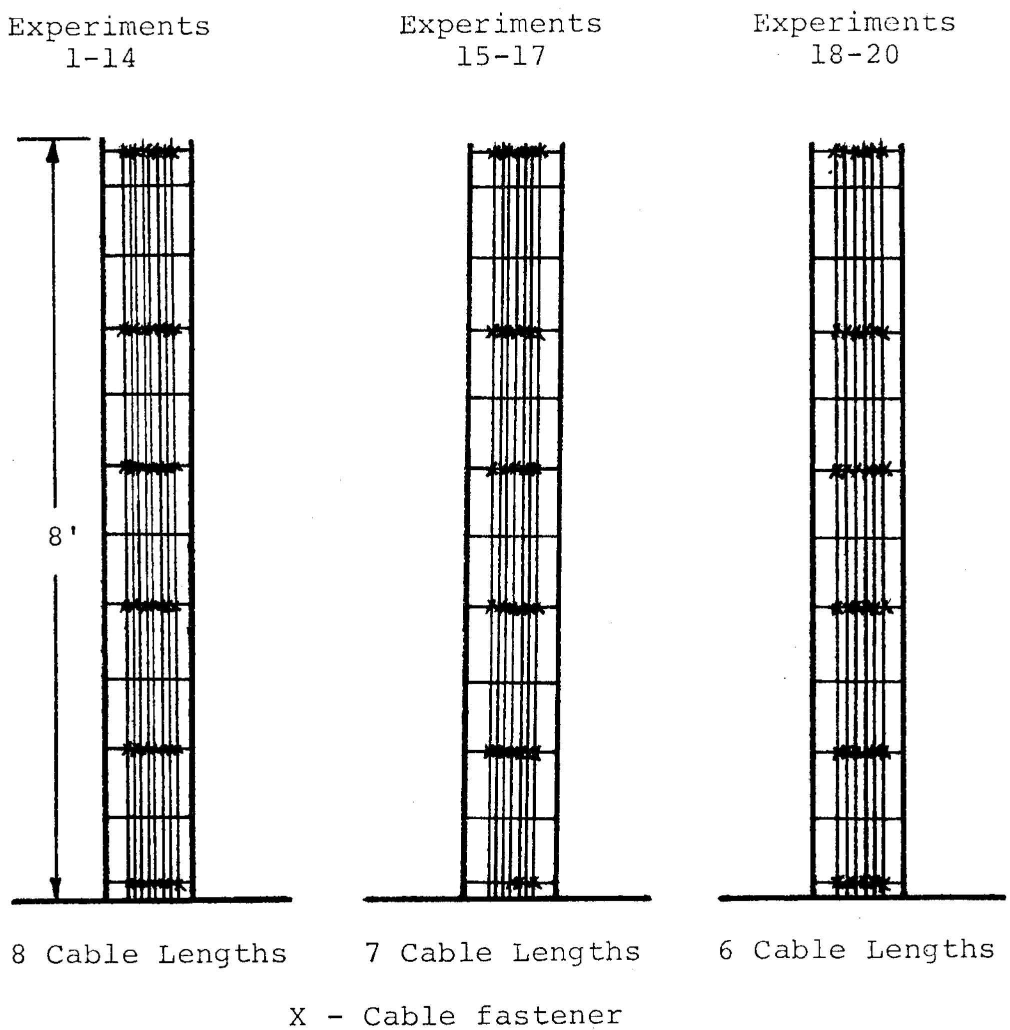
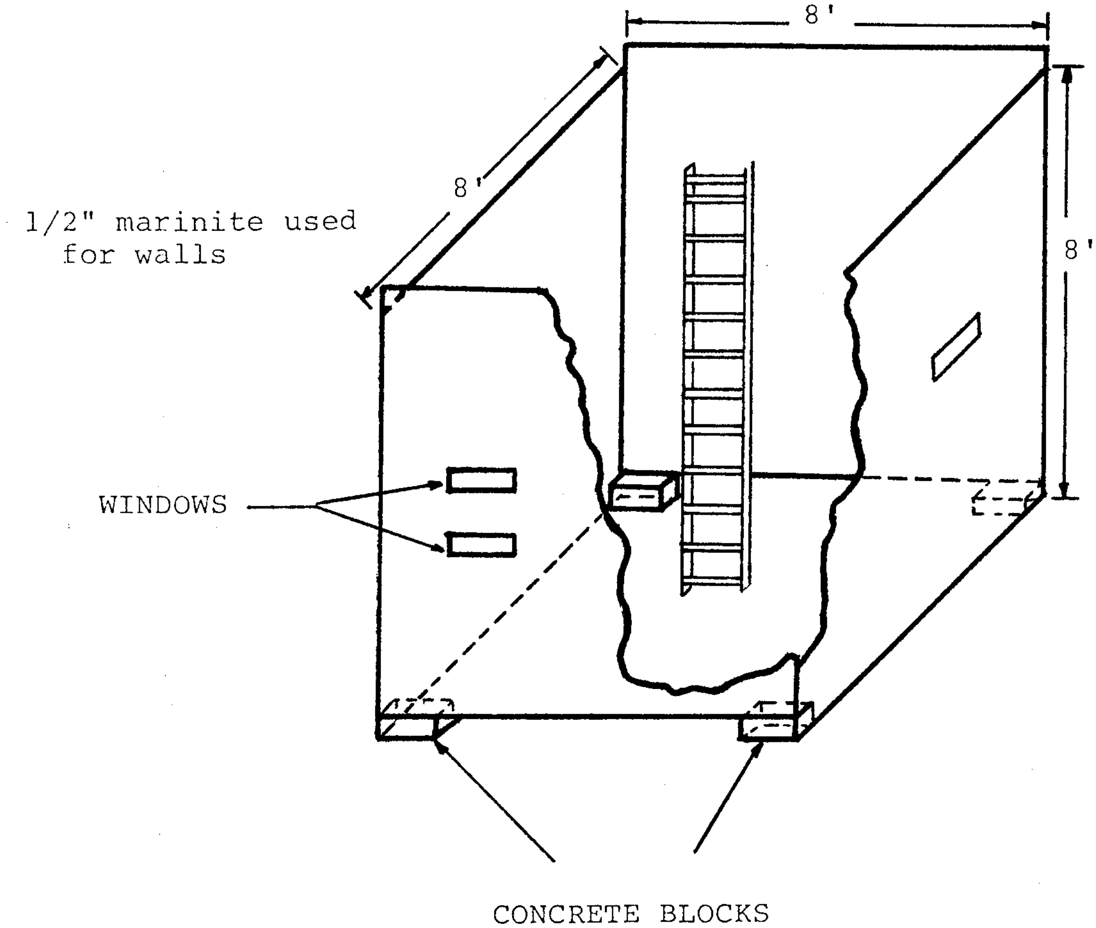


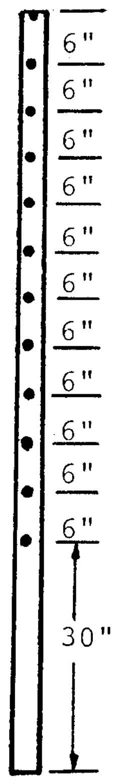
Figure 2 - Cable Tray and Cable Installation



Each Wall May Be Raised Or Lowered Independently

Figure 3 - Enclosure

Front Surface



• Thermocouple Location

Instrumented cable installed along the center line of the cable tray in Experiments 15-17, or 1/4 the cable diameter from cable tray center line in Experiments 1-4 and 18-20.

Figure 4 - Cable Jacket Thermocouples

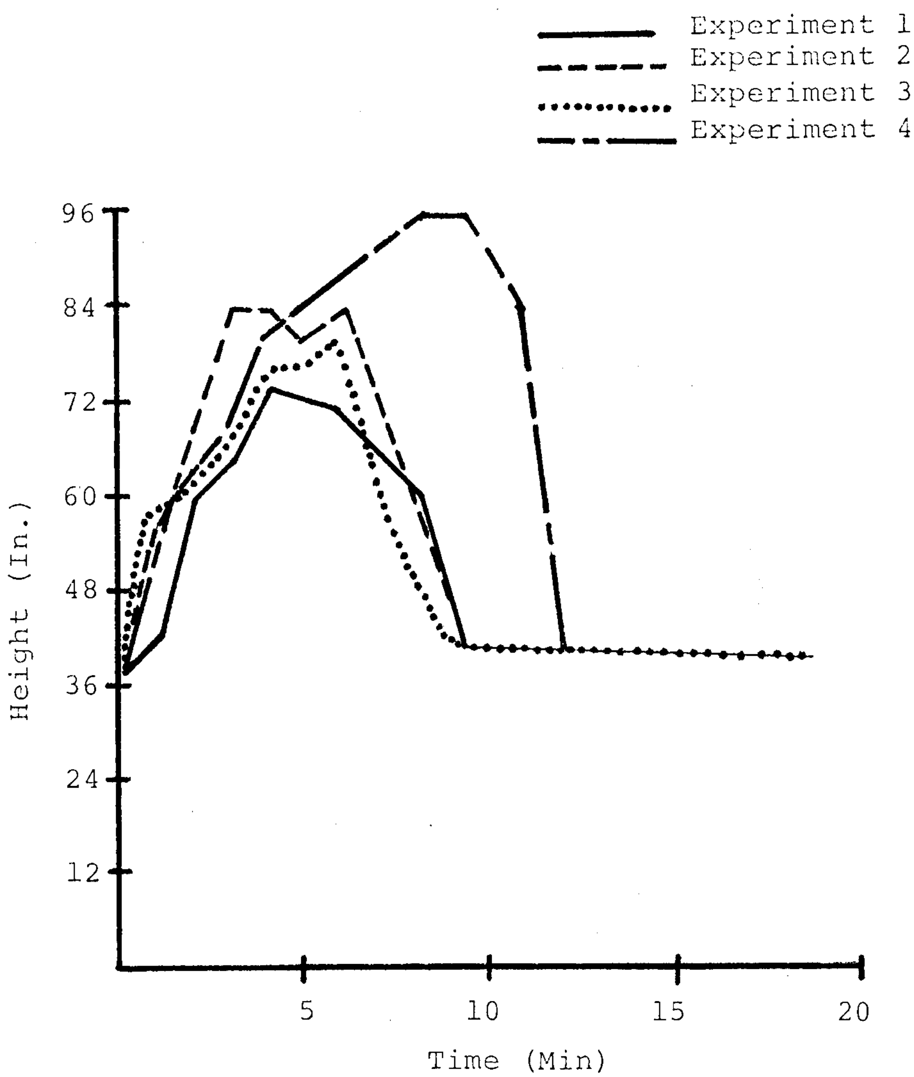


Figure 5 - Maximum Flame Height vs Time
Experiments 1-4

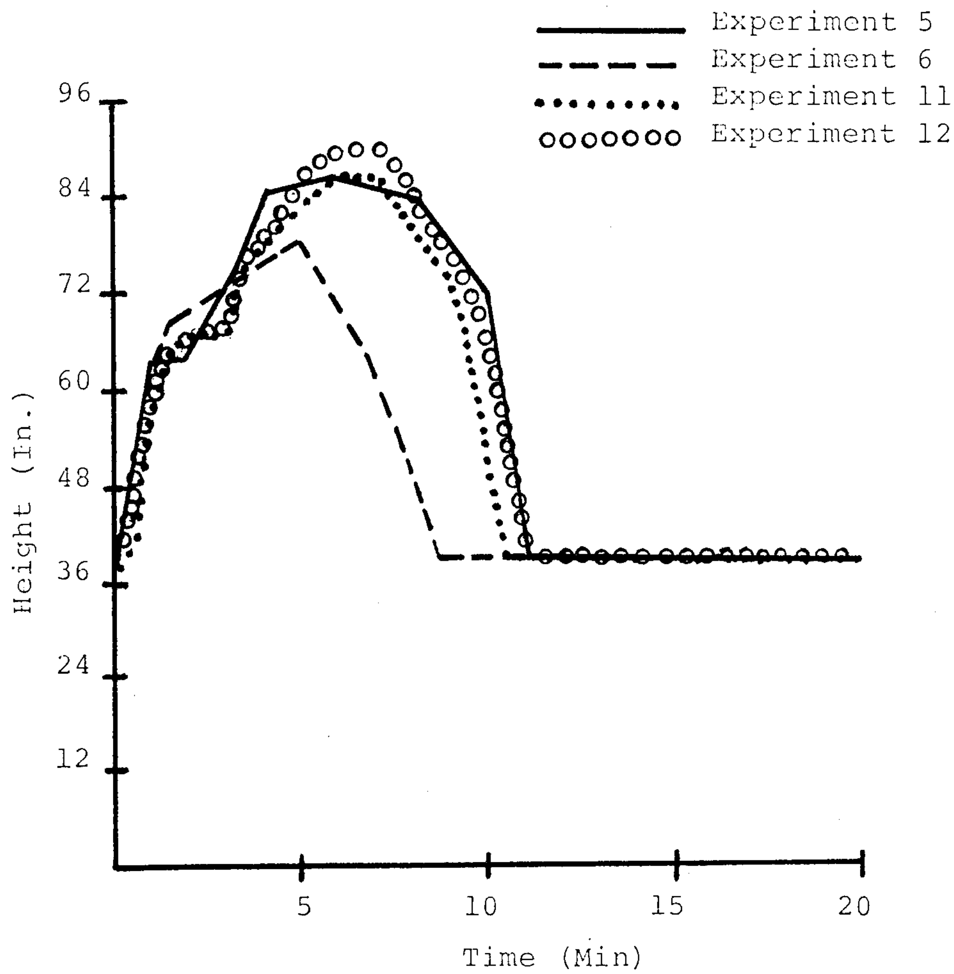


Figure 6 - Maximum Flame Height vs Time
Experiments 5, 6, 11 and 12

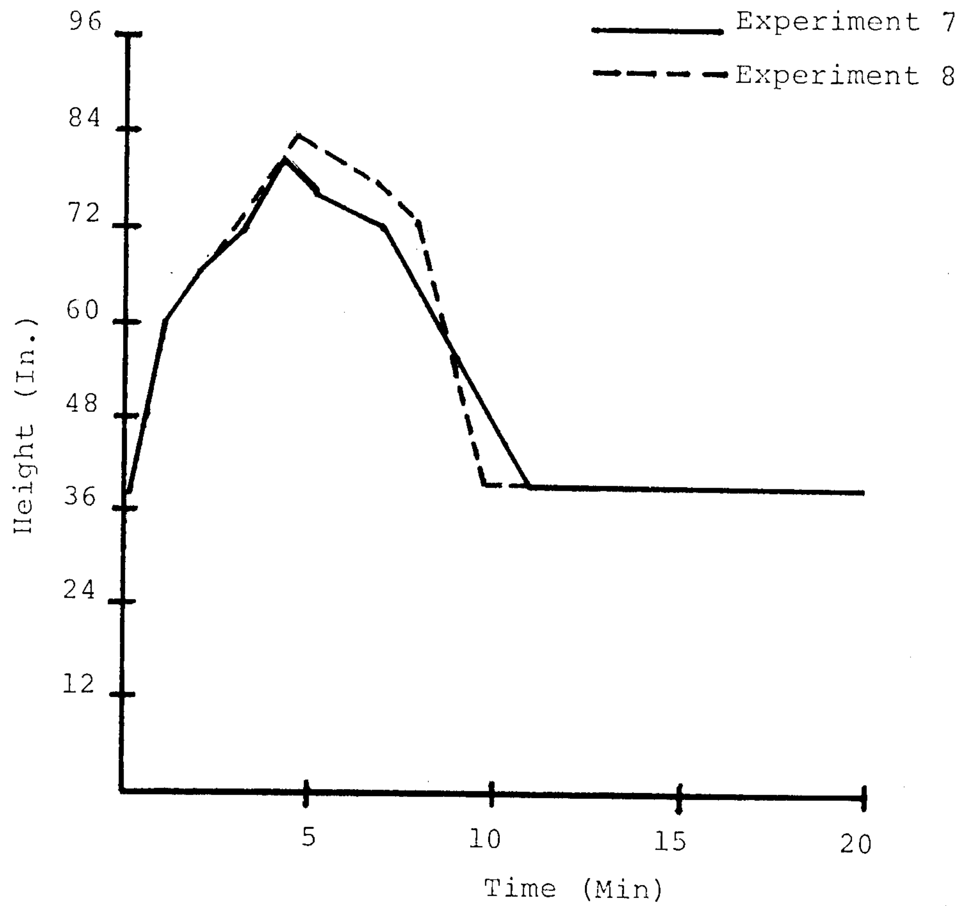


Figure 7 - Maximum Flame Height vs Time
Experiments 7 and 8

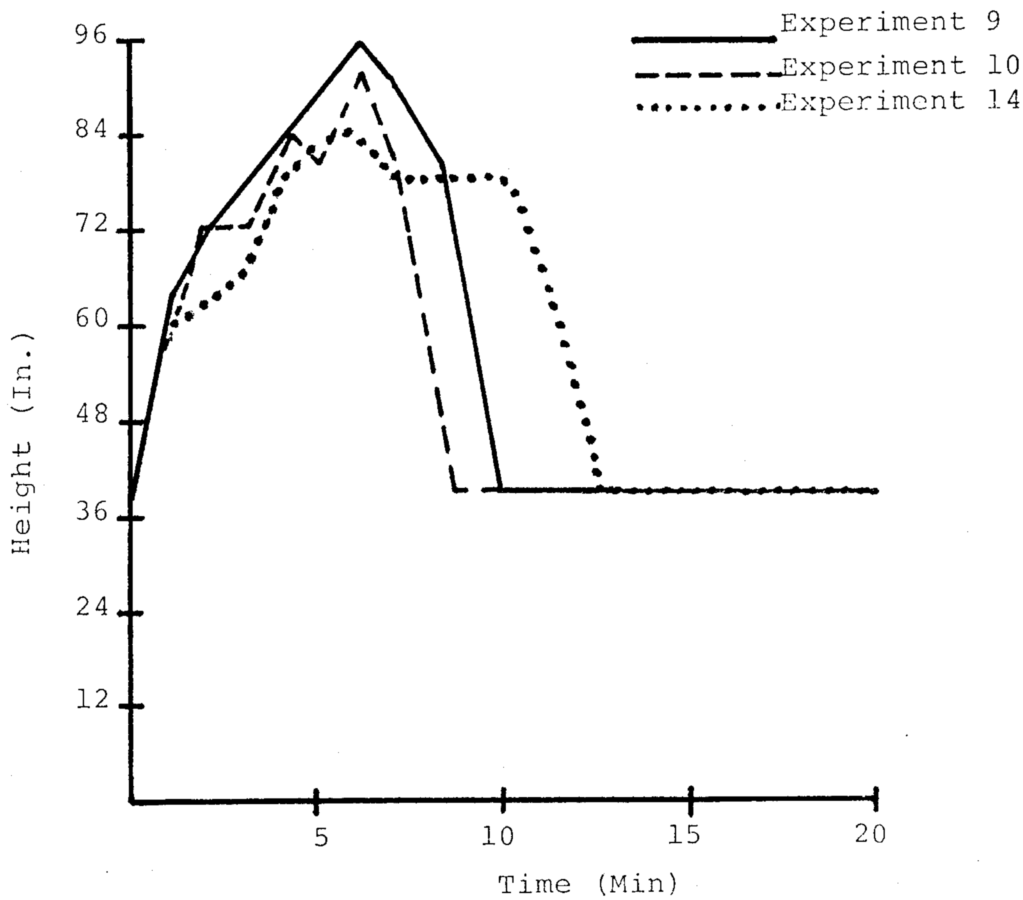


Figure 8 - Maximum Flame Height vs Time
Experiments 9, 10 and 14

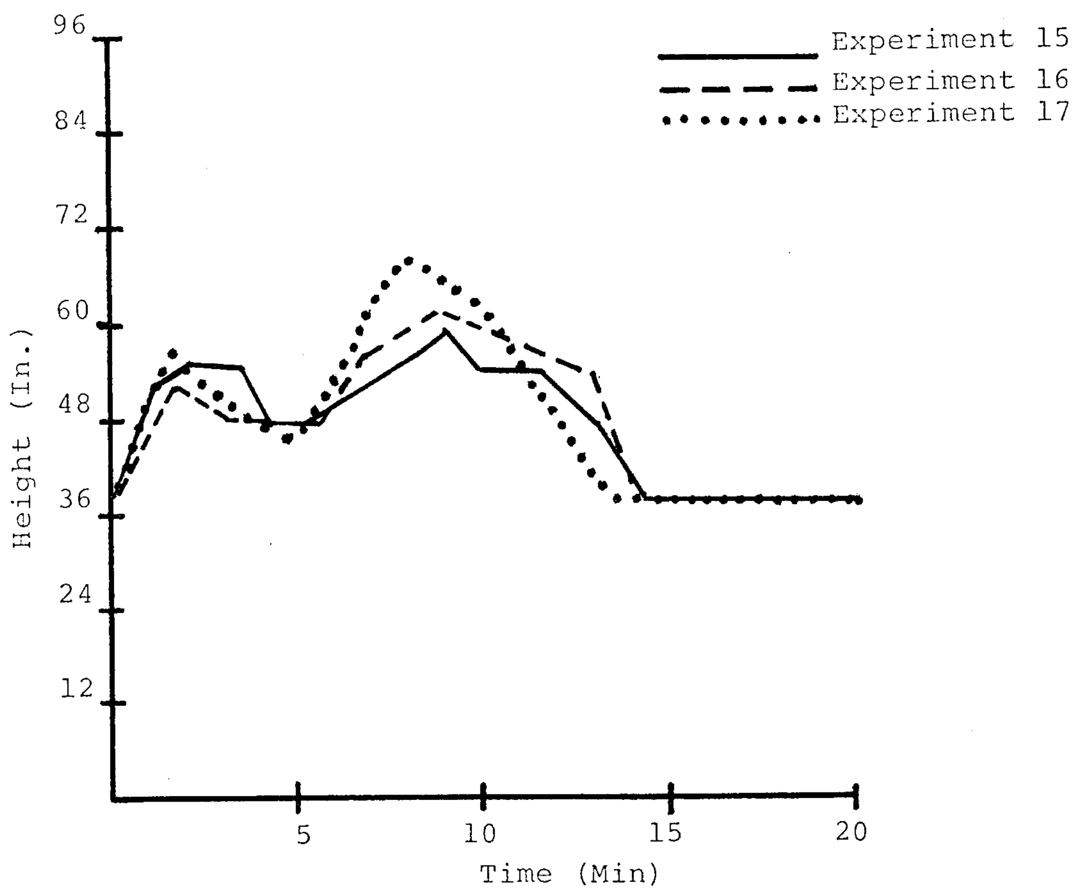


Figure 9 - Maximum Flame Height vs Time
Experiments 15, 16 and 17

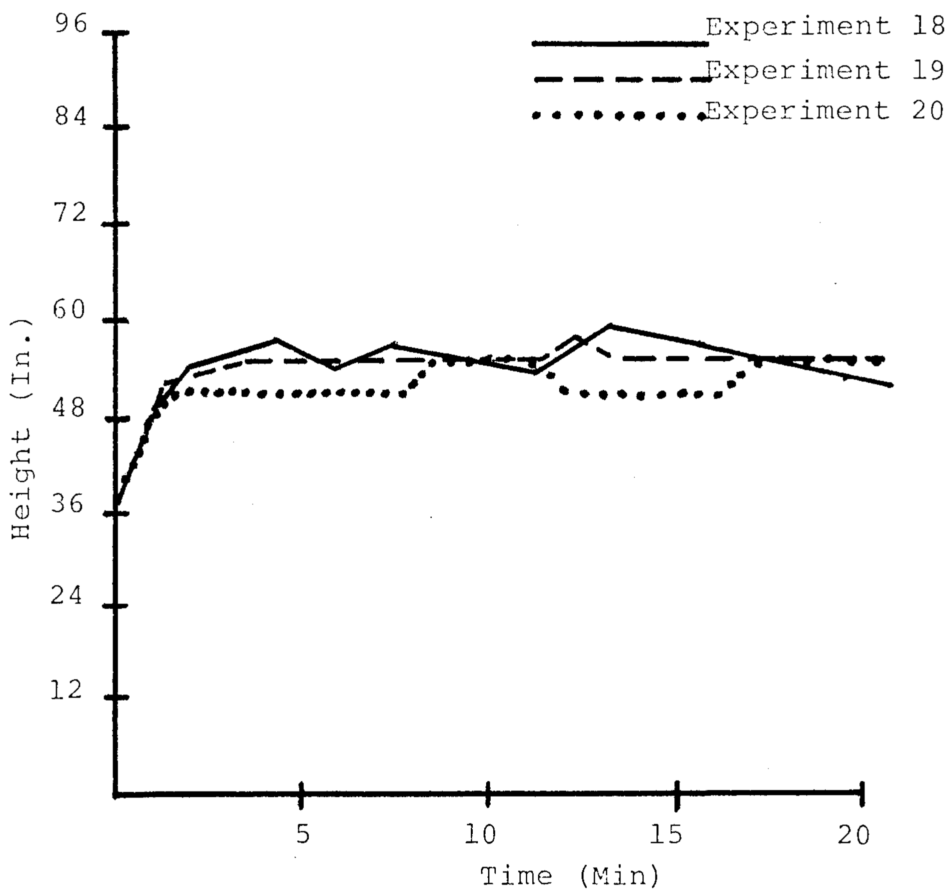
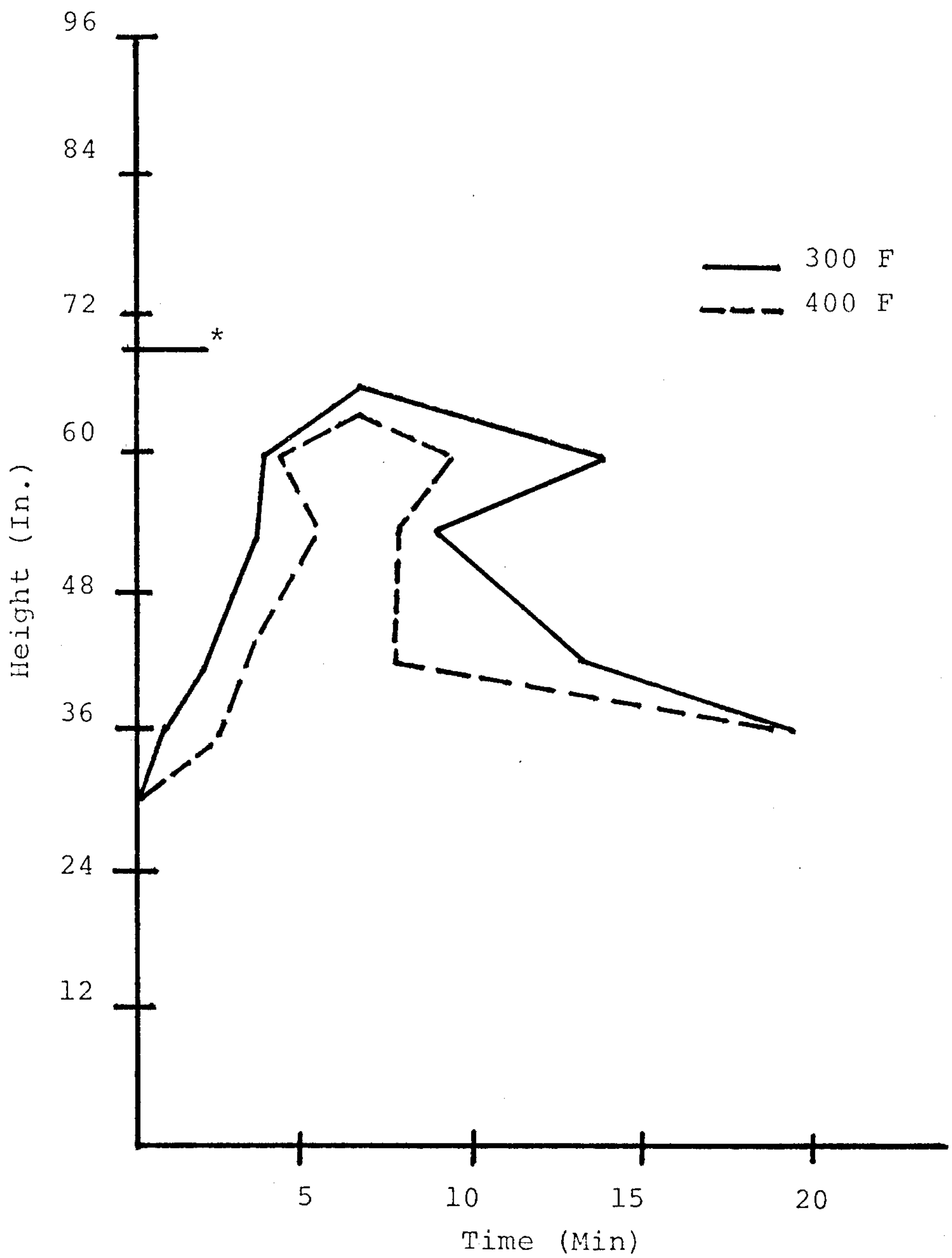
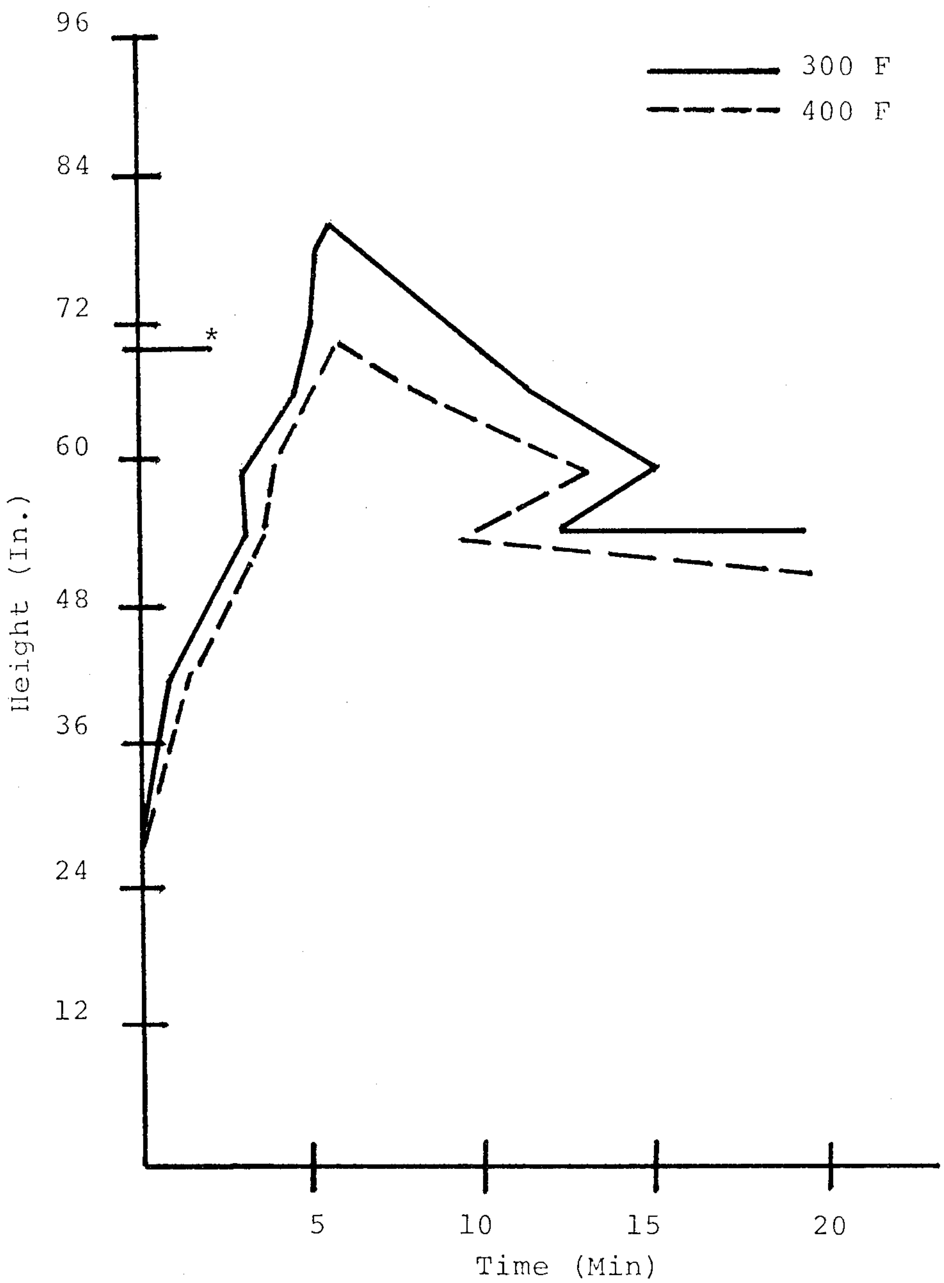


Figure 10 - Maximum Flame Height vs Time
Experiments 18, 19 and 20



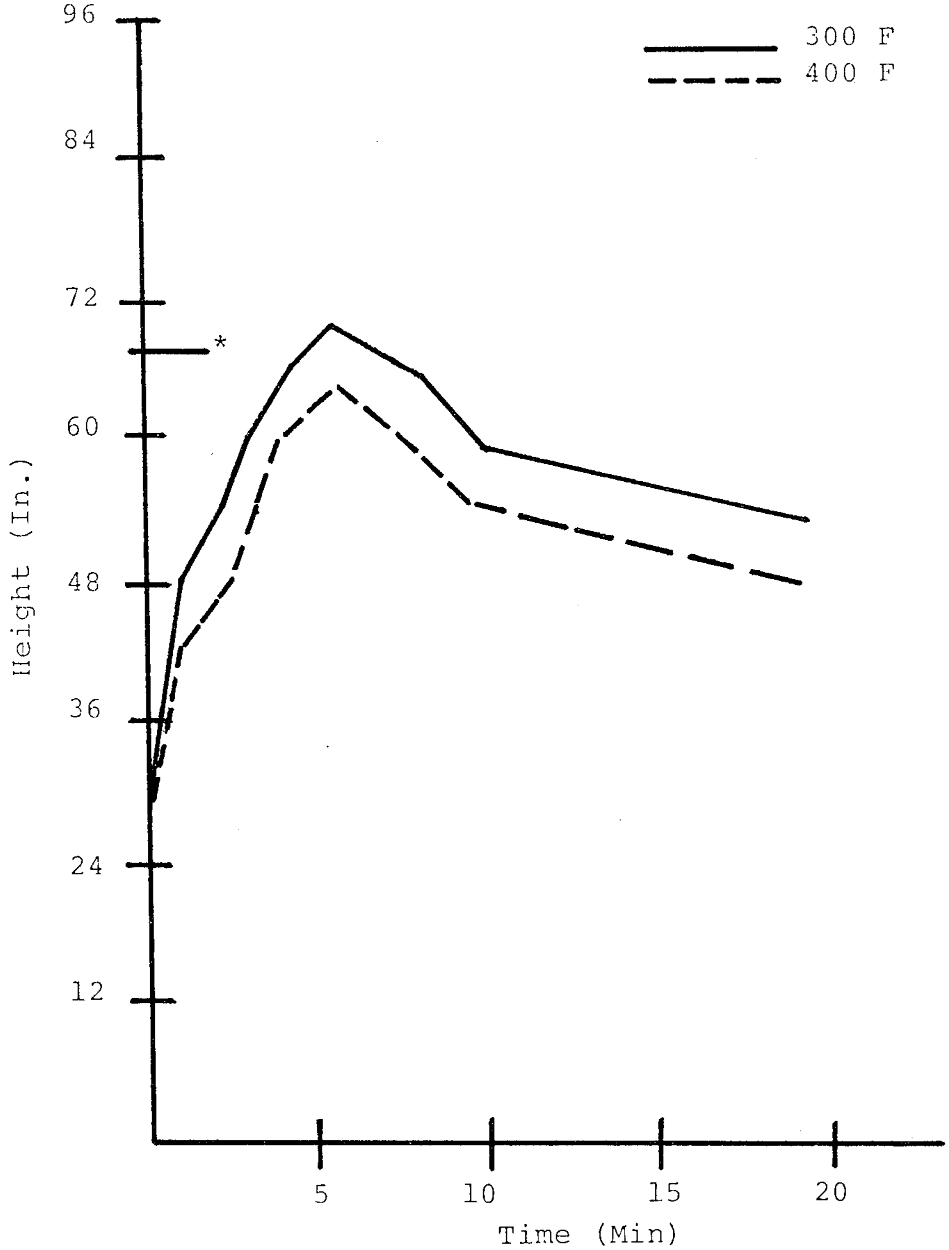
* - Maximum cable damage height.

Figure 11 - Cable Jacket Temperature
Experiment 1



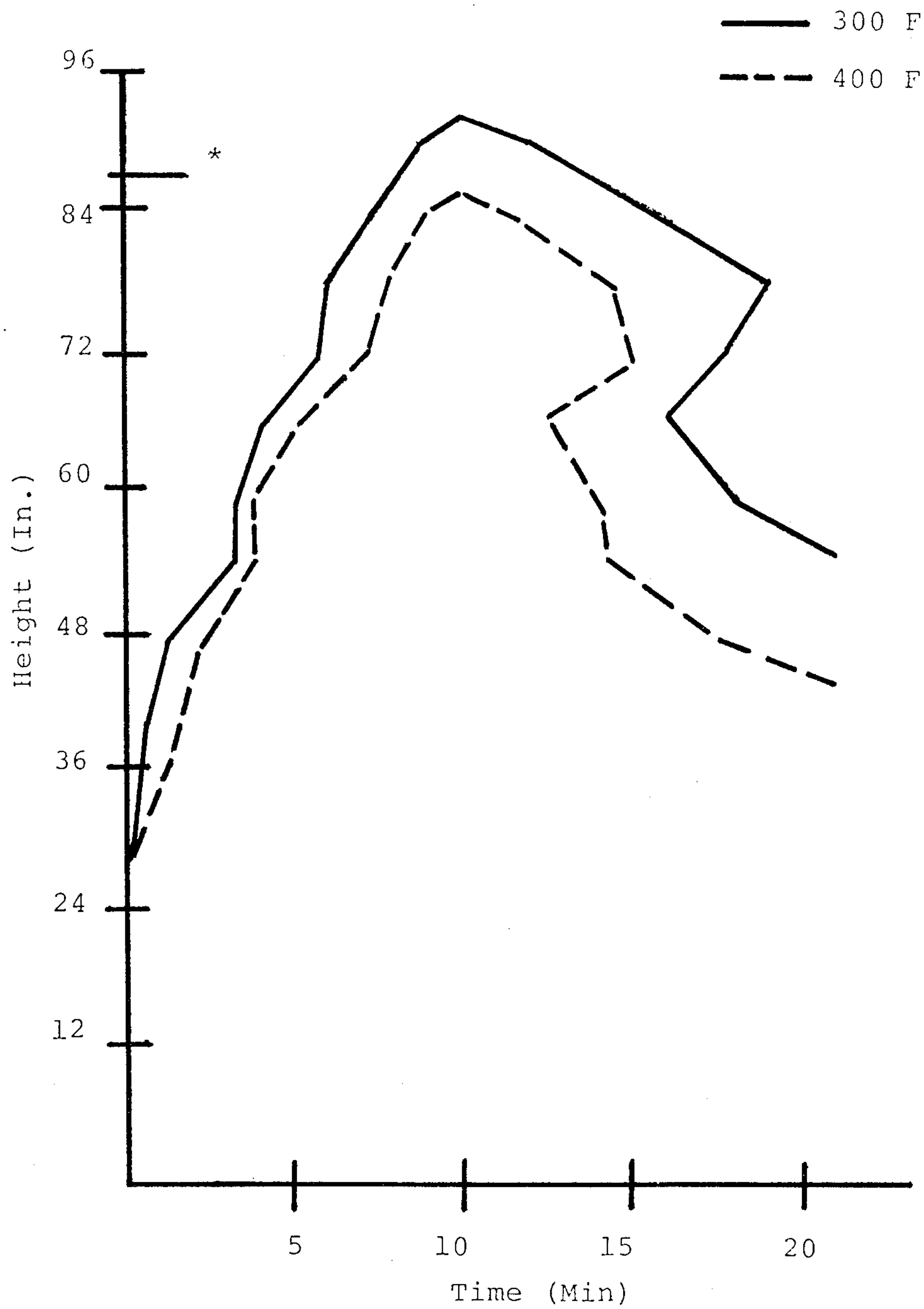
* - Maximum cable damage height.

Figure 12 - Cable Jacket Temperature
Experiment 2



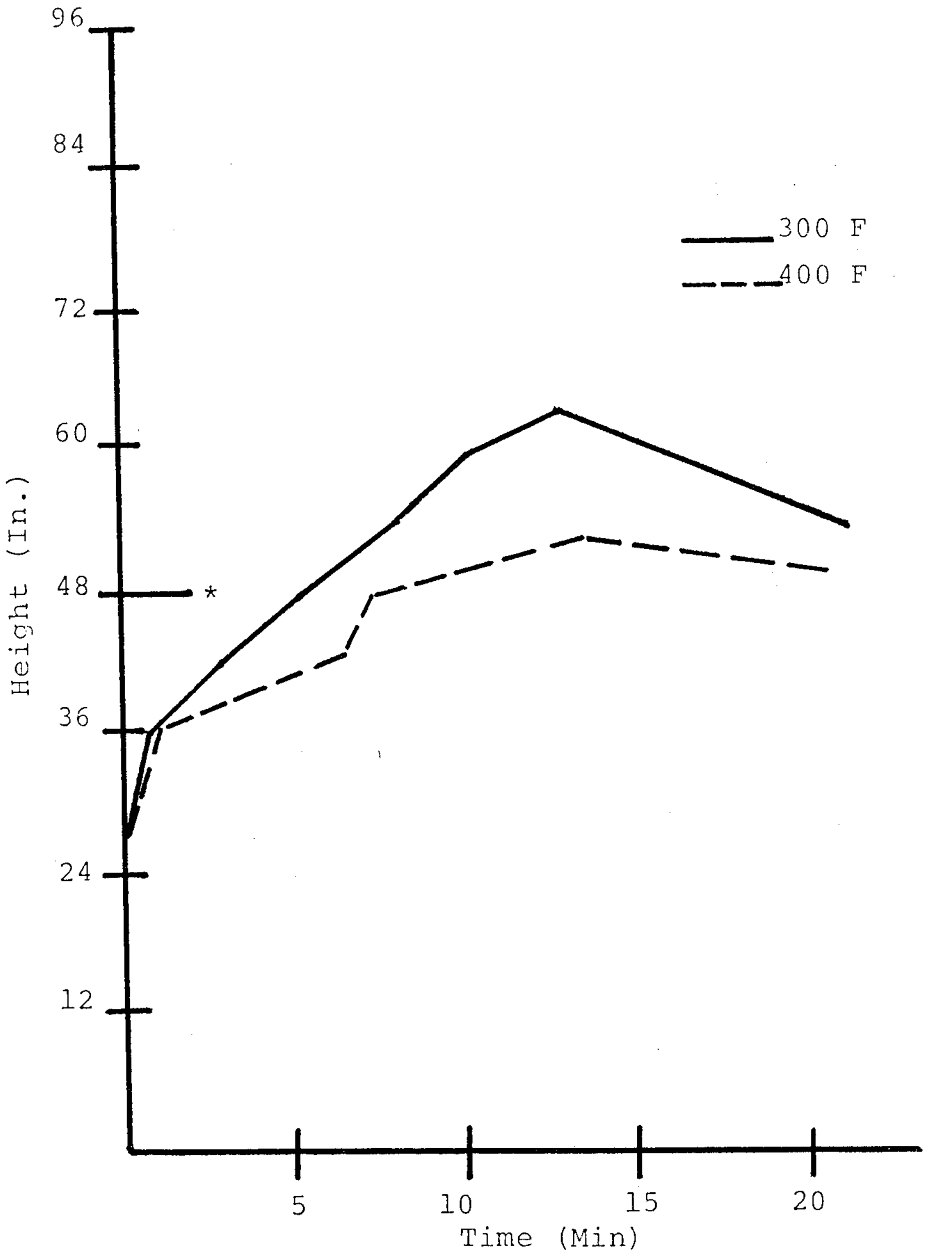
* - Maximum cable damage height.

Figure 13 - Cable Jacket Temperature
Experiment 3



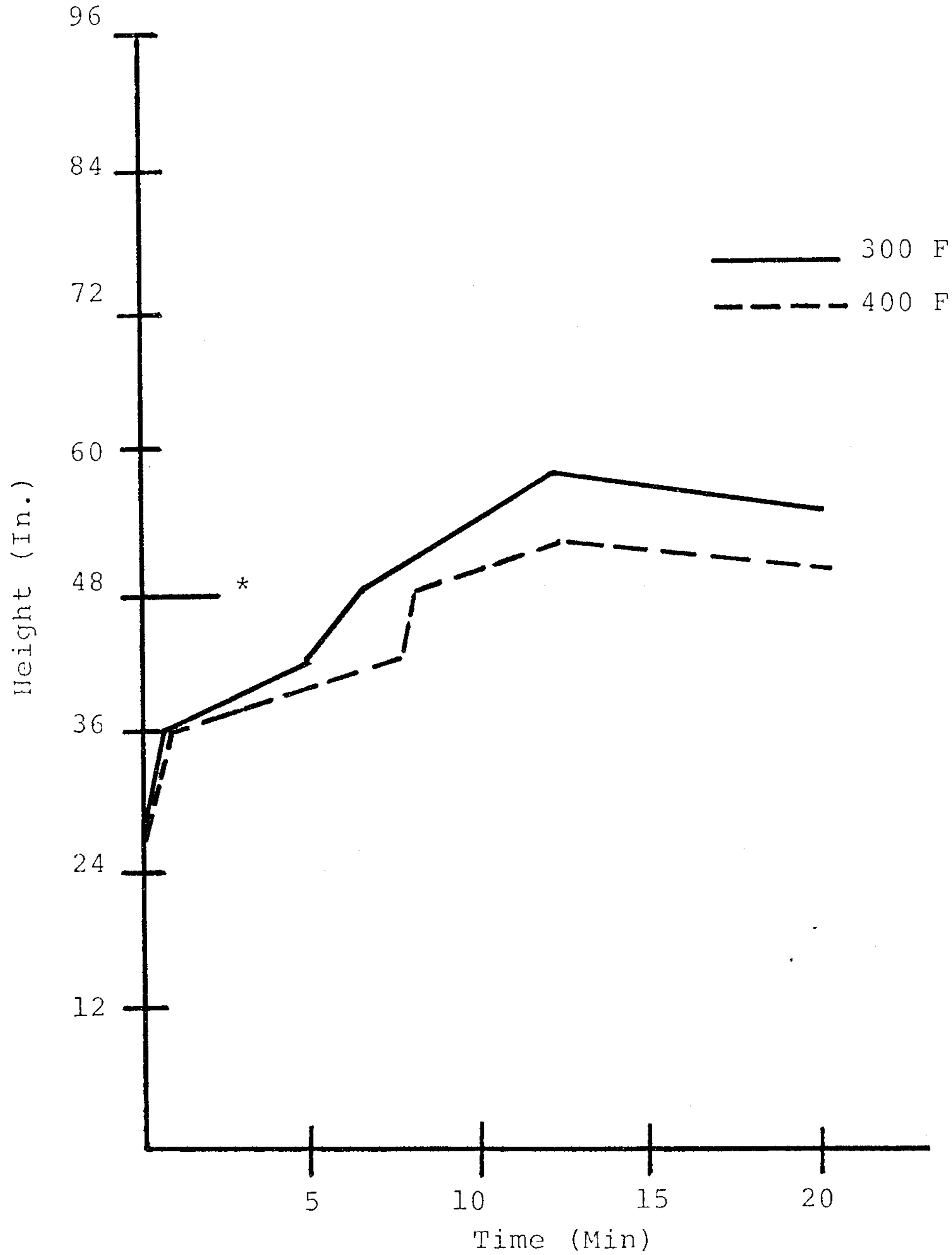
* - Maximum cable damage height.

Figure 14 - Cable Jacket Temperature
Experiment 4



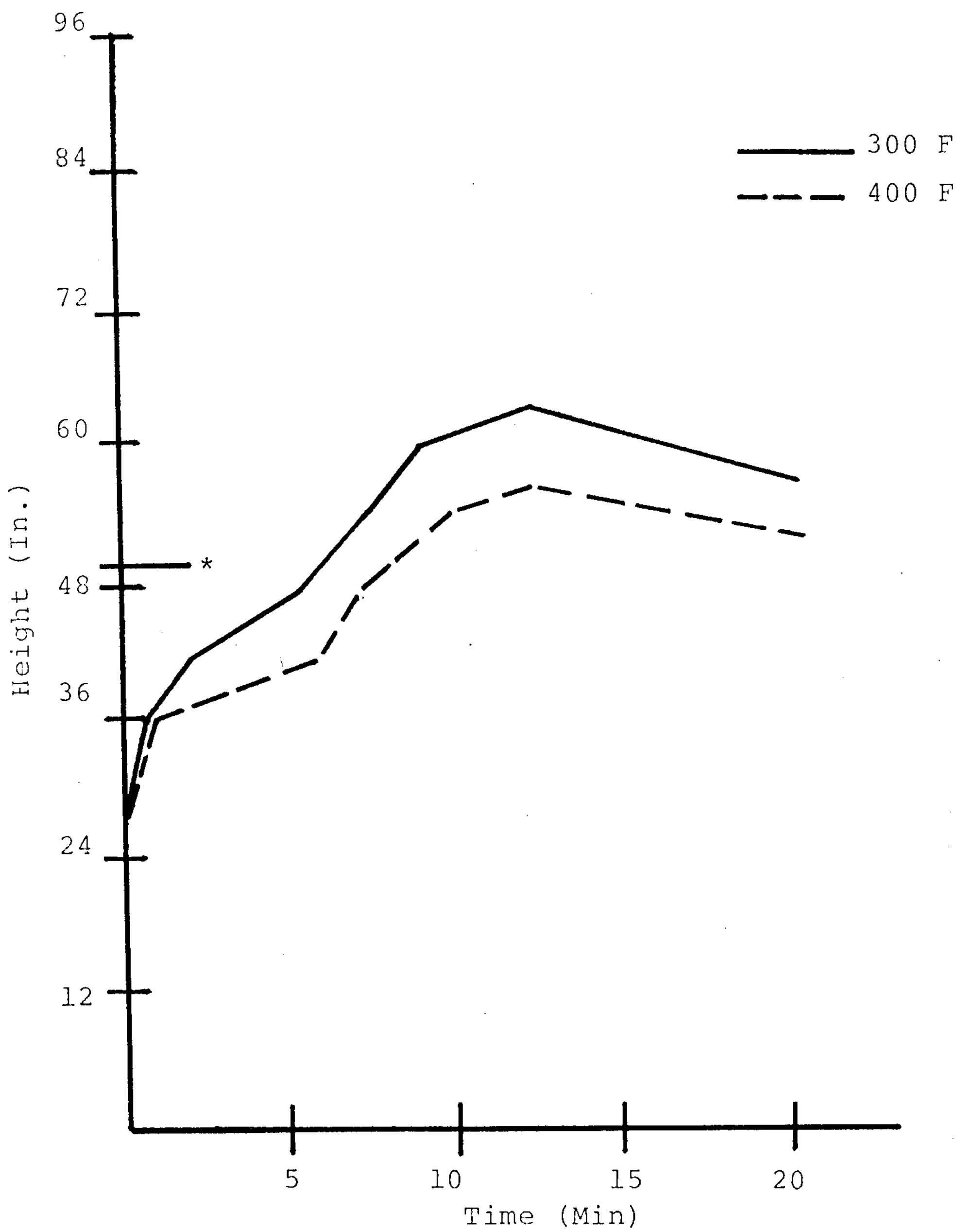
* - Maximum cable damage height.

Figure 15 - Cable Jacket Temperature Experiment 15



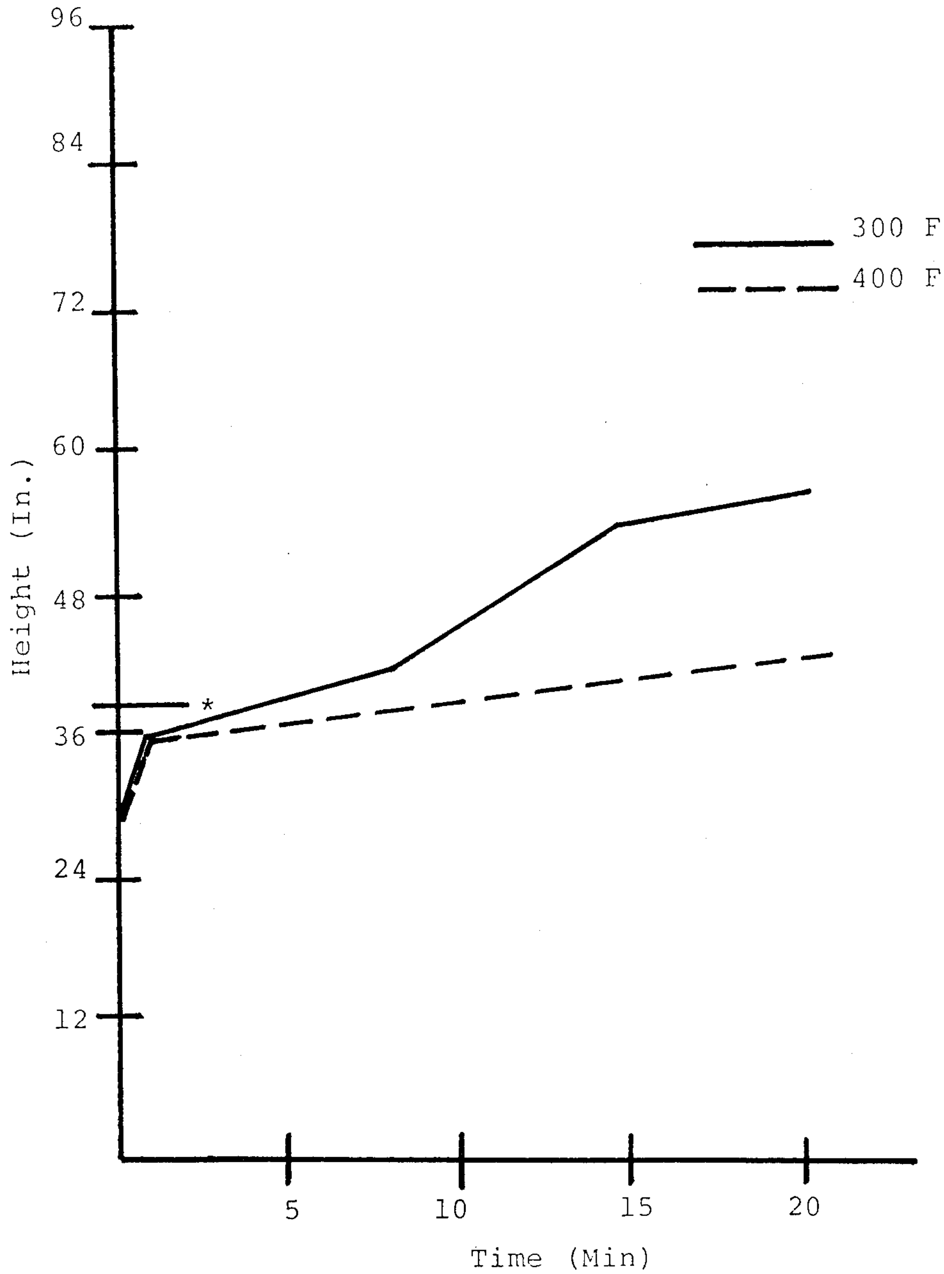
* - Maximum cable damage height.

Figure 16 - Cable Jacket Temperature
Experiment 16



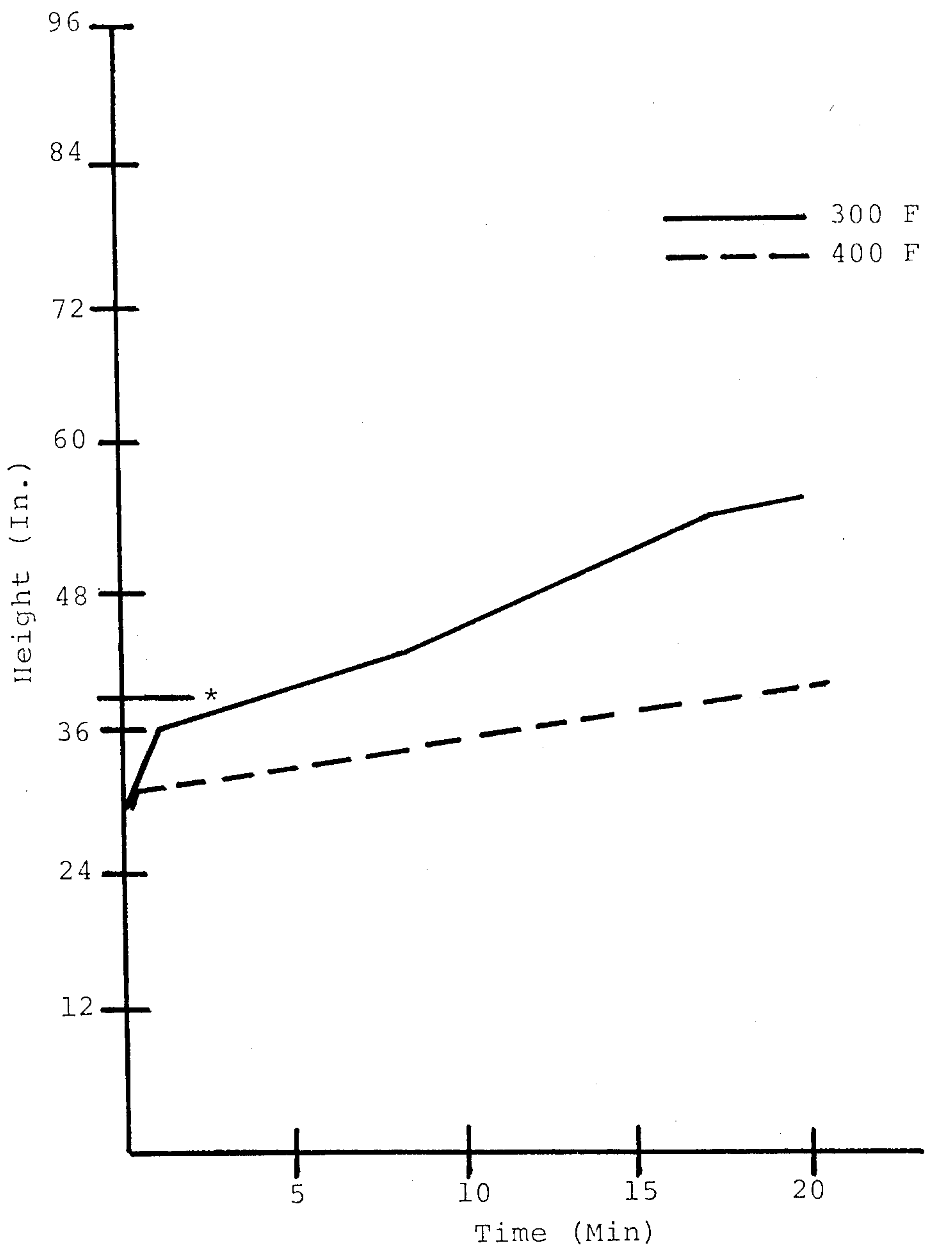
* - Maximum cable damage height.

Figure 17 - Cable Jacket Temperature
Experiment 17



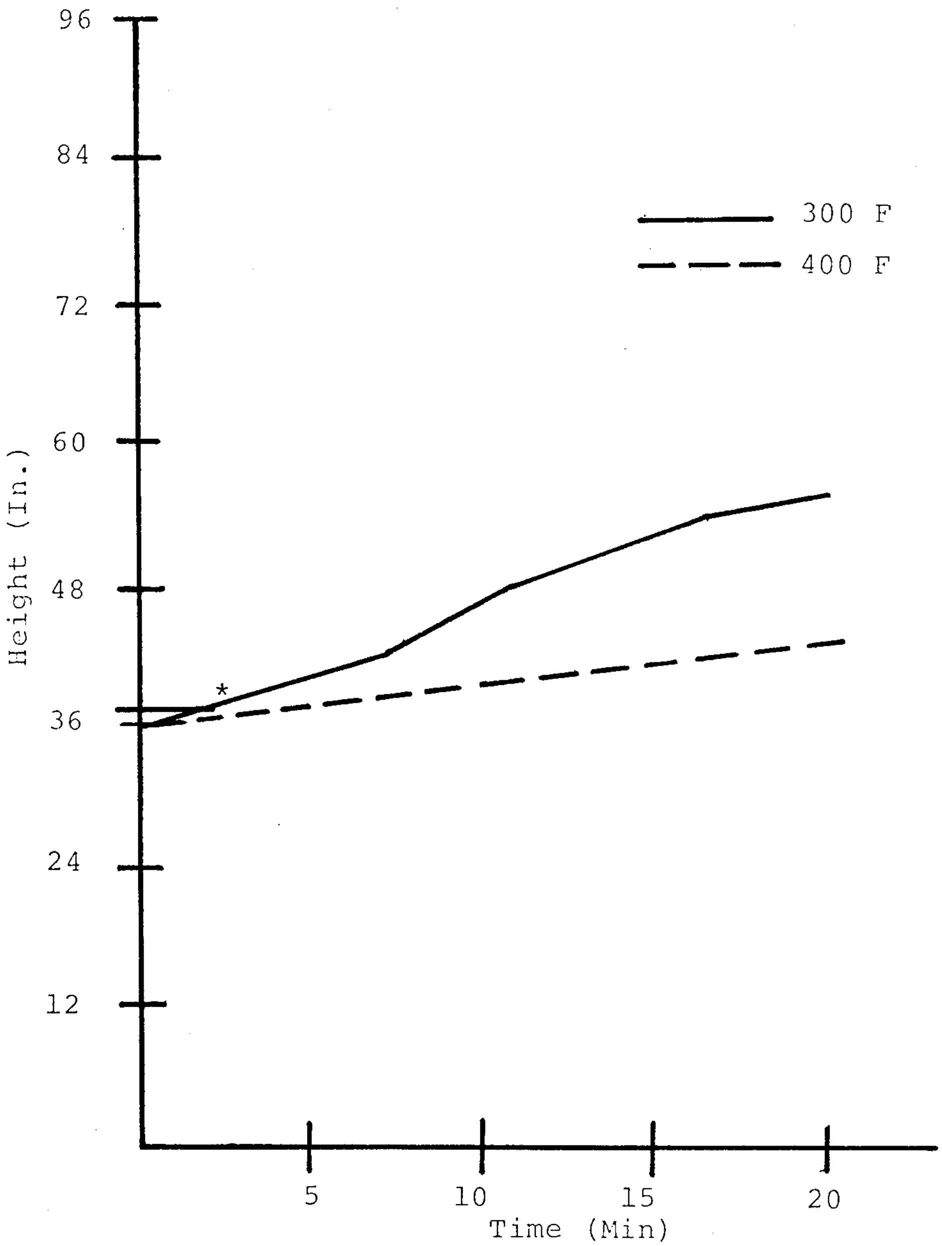
* - Maximum cable damage height.

Figure 18 - Cable Jacket Temperature
Experiment 18



* - Maximum cable damage height.

<u>Figure 19 - Cable Jacket Temperature</u>
<u>Experiment 19</u>



* - Maximum cable damage height.

Figure 20 - Cable Jacket Temperature
Experiment 20

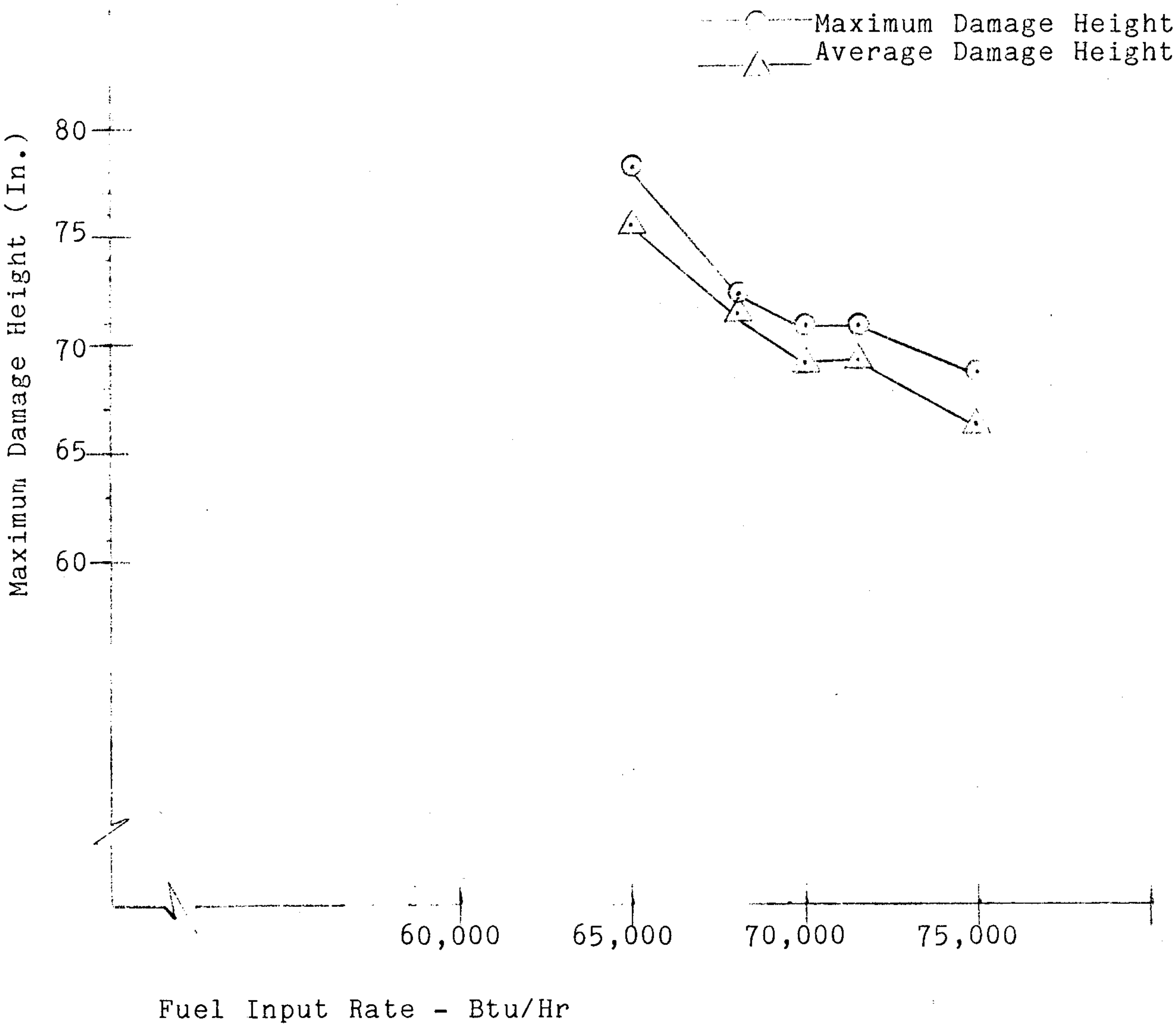


Figure 21 - Maximum Height of Cable Damage Versus Fuel Input

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Experiments were conducted to establish data on the sensitivity of the results to variations of several parameters of the vertical cable tray fire test described in the IEEE Standard 383. Parameters varied were burner-to-cable distance, air input rate and fuel input rate. As a result of these experiments and previous experience, suggestions for revision of IEEE 383 are made with respect to 1) construction of cable trays, 2) test enclosure, 3) type, size and spacing of cable ties, 4) burner position, 5) measurement of fuel and air rates, 6) flame temperature, 7) initial room temperature, and 8) reporting of results.

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